

NSTS 07700, Volume XIV,
Appendix 6
System Description and Design Data -
Mission Planning and Flight Design

DESCRIPTION OF CHANGES TO
SYSTEM DESCRIPTION AND DESIGN DATA - MISSION PLANNING AND FLIGHT DESIGN
NSTS 07700, VOLUME XIV, APPENDIX 6

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Preface

This document is designed to be used in conjunction with the series of documents illustrated in Figure 1. Information on Space Shuttle Program (SSP) mission planning and flight design is presented herein.

Specific agreements between the customer and the SSP must be specified in the individual payload integration plans.

Effective with the publication of this revision, configuration control of this document will be accomplished through the application of the procedures contained in NSTS 07700, Volume IV, Configuration Requirements Management.

Questions and recommendations concerning this document should be addressed to:

Manager, Customer and Flight Integration
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

Signed by Michele A. Brekke

Michele A. Brekke
Manager
Customer and Flight Integration

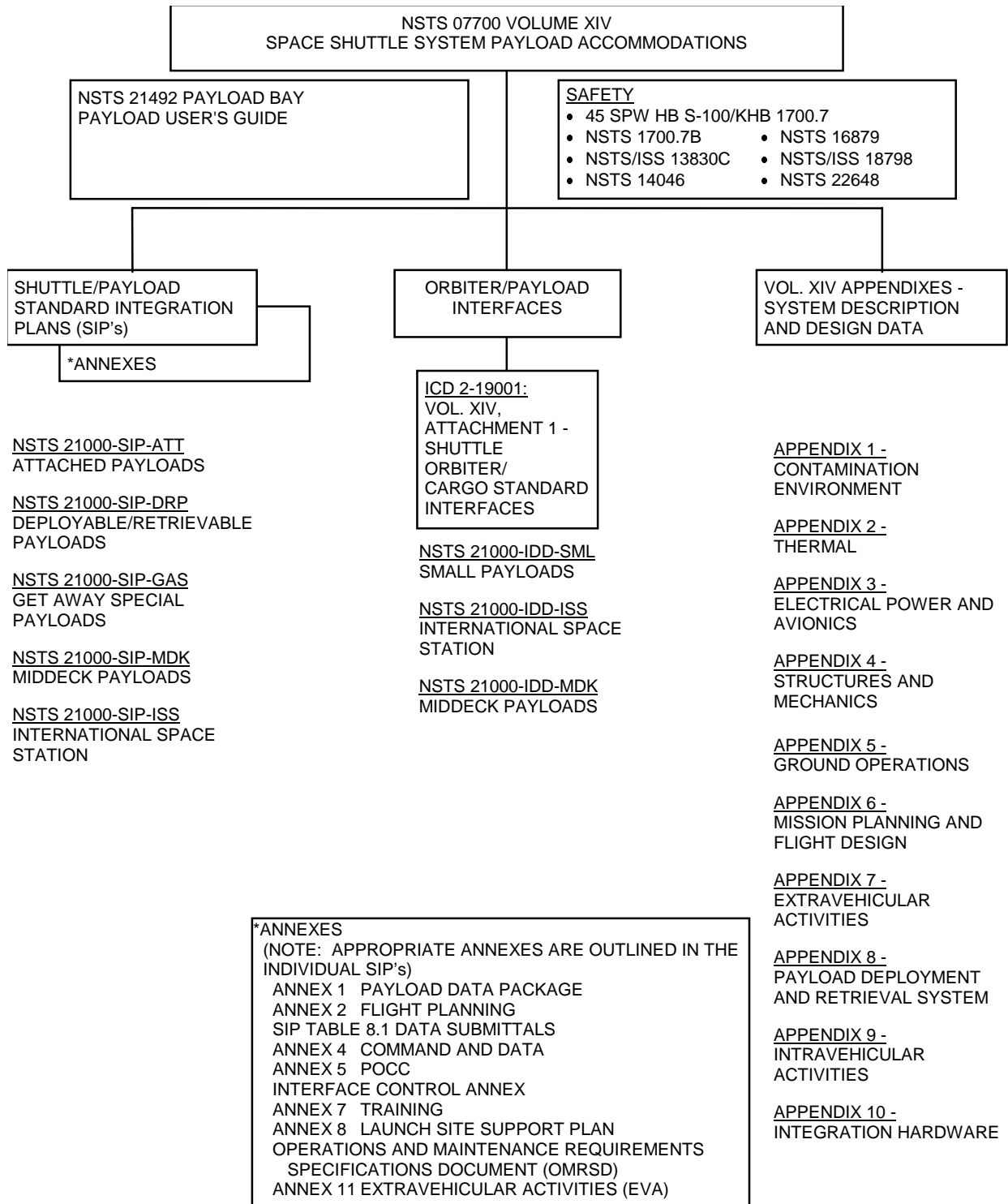


Figure 1.- SSP customer documentation tree.

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Introduction

1

This appendix was written to assist the customer with mission planning and flight design matters, especially as they pertain to completing the Integration Plan (IP). The IP can be a payload integration plan (PIP), a mission integration plan (MIP), or a carrier integration plan (CIP). The IP is the technical contract with the customer that contains the agreements by which a payload is integrated with the rest of the cargo and the Space Shuttle. (See Space Shuttle System Payload Accommodations, NSTS 07700, Volume XIV.) IP Annex 2, Flight Planning provides the Space Shuttle Program (SSP) with the customer's flight design and crew activities requirements.

IP Annex 2 comprises three parts. Part I contains agreements between the customer and the SSP on matters which relate to payload electrical power, energy, cooling, and Orbiter support equipment usage. Part II includes an outline of the customer's crew-related activities, attitude and pointing requirements, contamination constraints, photographic and television events, and extravehicular activities for inclusion in the Flight Plan. Part III deals with trajectory design and deployment target considerations.

Mission planning and flight design is the preparation of trajectory, attitude, consumables profile, and crew timeline for a specific flight. Most payloads can avoid the expense of a dedicated Shuttle flight by sharing resources. To do so successfully, it is important that customers design to SSP standard interfaces and requirements as defined in SSP customer documentation. (See Figure 1 in the Preface.)

Payloads are integrated into a cargo on the basis of payload-to-payload mutual compatibility. Since manifesting is an SSP function, the customer can best increase the chances of satisfactorily completing the Cargo Integration Review (CIR) by designing to these standards. (The CIR process is outlined in Cargo Integration Review Plan, JSC 19645.)

1.1 Dedicated Flights

Dedicated flights involve a single customer who has purchased the SSP services for the duration of a flight. Dedicated flights may be necessary when performance or service requirements demand. In the absence of other payloads, the customer need only consider Space Shuttle limits on resources or capabilities.

1.2 Shared Flights

Shared flights involve multiple payloads, each utilizing only part of the SSP services. Shared flights may carry crew compartment payloads and payload bay payloads, which may include attached payloads, deployable payloads, retrievable payloads, and revisit (or on-orbit serviceable) payloads, each with their own requirements. Customer adherence to the standard requirements is essential to the payload's mixability with the rest of the cargo and its compatibility with the Orbiter.

Orbit Requirements

2

2.1 Orbital Parameters

A range of standard SSP orbits is available. At an inclination of 28.45 degrees to the equator, altitudes may range from 160 to 330 nautical miles (nmi). At an inclination of 39 degrees to the equator, altitudes may range from 150 to 165 nmi. At an inclination of 51.6 degrees, altitudes range from 120 to 125 nmi or 170 to 180 nmi. And at an altitude of 57 degrees, altitudes range from 127 to 320 nmi. The standard orbit is near-circular to account for minor variations in altitude due to performance dispersions, perturbations, and required orbital maneuvering. The variation from circular altitude is typically 3 nmi or less at the time of insertion.

Payload objectives that cannot be met with the standard orbit may still be achievable by using a unique altitude or inclination or both. But special analysis and charges will be necessary for the nonstandard orbit. In general, variations in altitude are easier to accommodate than variations in inclination, the latter being heavily constrained by launch performance and range safety limitations. The range of allowable inclinations for Eastern Test Range (ETR) launches is illustrated in Figure 2-1. Customers with unique altitude requirements for shared payloads should be prepared, if possible, to specify the maximum and minimum altitudes that meet their needs.

Utilization of the standard orbit assures compatibility with other payloads, enhances manifest opportunities, and allows use of standard trajectory design data.

Customers will be expected to quantify the constraints that influence launch window in the IP and Annex 2.

Each customer should provide the largest possible launch window of at least three hours in duration (centered around 1530 Greenwich Mean Time (GMT)) to allow manifesting options. This type of window, consistent with Orbiter preferred lighting constraints, guarantees the greatest likelihood of launch success. A payload's launch window constraints will be combined with those of other payloads, if any, and the normal operating constraints of the Orbiter itself, to produce a composite window for each planned mission.

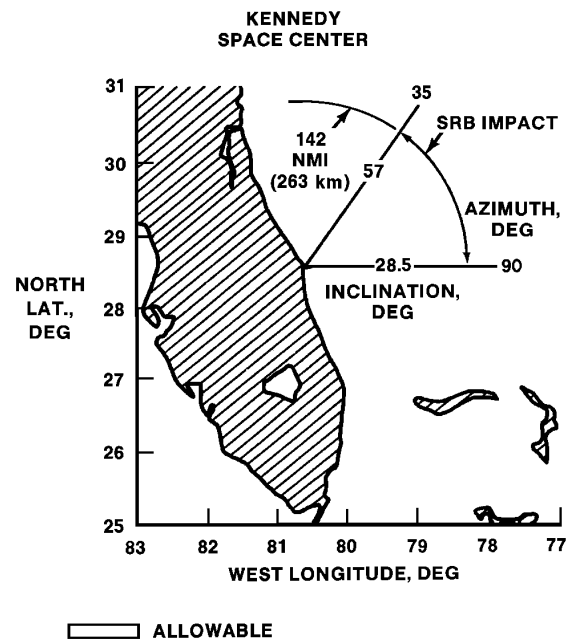


Figure 2-1.- Inclination capability

2.2 Launch Window

Payload operating constraints or objectives that may influence the Shuttle launch window should be identified early. Typical factors that may affect launch window are payload injection constraints, specified orbital timing or lighting, astronomical sightings, or rendezvous requirements.

Crew Time

3

Mission planning for payload activities involves a variety of considerations for all mission phases. The phases of ascent and entry provide no opportunity for crew actions associated with payloads. Since no crew-initiated nominal operations take place during these phases, there are no general operational considerations that add to the requirements stated in other documents. Because of this, this section will deal only with the phases of post-insertion, on-orbit, and deorbit preparation.

No definitive statement can be made regarding crew availability for any mission until preliminary mission plans are developed. However, the constraints used in developing the crew timelines are documented in the shuttle Crew Scheduling Constraints, NSTS 37326. Some factors affecting the planning of crew work schedules are summarized below.

The principal considerations which drive crew schedules are Shuttle operational activity, crew physiological factors, and payload requirements. The amount of crew time available for payload operations on any given day depends on total mission duration, which may affect crew day length. Reasonable crew circadian shifts are implemented to accommodate the required deorbit opportunities. The number of crewmembers assigned and the needs of other shared cargo components will also determine crew availability. Mission duration and the size of the crew are established by the SSP.

For typical single-shift operations, crew time is allocated for crew sleep and meals. Additionally, dedicated time is provided for pre- and post-sleep Orbiter configuration and crew personal hygiene, as well as daily periods of exercise for all NASA crewmembers. This results in 7.5 hours per day available for crew interaction with payloads. Launch day duration is reduced by the crew prelaunch awake time. Post-insertion activities further reduce crew availability on launch day. Similarly, at the end of a mission, activities such as

cabin stowage and deorbit preparation also reduce crew time for payload operations. Details of these considerations are included in NSTS 37326.

Another staffing option for Space Shuttle missions involves the use of two teams of crewmembers operating on opposing shifts. This is referred to as dual shift ops. This variation is available only in unique situations negotiated on a case-by-case basis with the SSP. Use of this approach may result in additional constraints on payload activities (due to a sleeping crew team) as well as a reduced number of crewmembers available on each shift.

Communications and Control

4

Payloads requiring extensive communications with the ground for operations should include Space Shuttle compatibility as a mode of their RF communications system. This capability will yield significant mission planning and flight design flexibility over any other communications mode.

4.1 Orbiter/Payload Communication System Compatibility

The Orbiter provides a dedicated payload communications system capable of interfacing with a payload via hard line or RF. For free-flying payloads, the Orbiter Payload Interrogator may be employed in either of two modes, standard or bent-pipe, depending on the characteristics of the payload transmitter. The standard mode is described in more technical detail in System Description and Design Data - Electrical Power and Avionics, NSTS 07700, Volume XIV, Appendix 3.

The standard mode provides the advantage of not competing with the Orbiter for Tracking and Data Relay Satellite System (TDRSS) coverage, and will in most cases eliminate any special attitude requirements for communications. Ku-band bent-pipe mode allows the payload to transmit to the ground at higher data rates; but this mode also places much greater restrictions on Orbiter operations. Bent-pipe Orbiter data relay should be restricted to accommodating noncritical data (such as science data or recorder dumps) and engineering data streams the rates of which are above the limit for the standard mode. The operational impacts of using the bent-pipe mode are significant due to:

- (1) the single string nature of the Ku-band system,

- (2) the additional attitude requirements to provide a line-of-sight for the Ku-band antenna to a Tracking and Data Relay Satellite (TDRS),
- (3) potential sensitivity of the payload, or other shared cargo, to Ku-band radiation, and
- (4) inability to display payload data on multifunction cathode ray tube (CRT) display system (MCDS).

Where payloads require direct communications with the TDRSS, these communications scenarios should be limited to short periods of time, such as during initial activation or, if the payload is deployable, just prior to release. This will limit the impacts to the thermal timelines of the other cargo elements on the same flight, since TDRS pointing is generally a deep-space attitude. Those payloads requiring RF checks with a space network station or customer ground site will normally have these activities scheduled early enough in the mission so as not to constrain selection of deployment opportunities.

4.2 Onboard Payload Data Processing

The only circumstances where the customer is required by the SSP to provide crew access to payload telemetry parameters is for safety-critical payload subsystems. Any additional requirements for such services will usually develop as the customer designs the joint Space Shuttle/payload operations scenario. While in many cases Orbiter access to payload telemetry is not required, it can contribute significantly to the potential for mission success in many operations scenarios. This data can include spacecraft pre-deploy checkout parameters, go/no-go remote manipulator system (RMS) release data, and payload-to-Orbiter interface indicators.

Once the customer has determined that he will use onboard data processing, SSP personnel will work

with the customer and flight crew in developing the crew display requirements in concert with refinement of the payload operating procedures. The SSP will also work with the customer to define adequate crew training requirements.

Indirectly related to onboard data processing is the use of the standard switch panel (SSP) for payload command and control. The customer should be aware that the status of SSP switches and talkbacks are not available in the Orbiter downlink. More details about the SSP can be found in NSTS 07700, Volume XIV, Appendix 3.

4.3 Ground Commanding

Any time-critical commanding required to perform any operation critical to the health of the payload may be more adequately provided from the Orbiter aft flight deck (AFD). This has the distinct advantage of not relying on the availability of the forward link from the ground. In addition, the flight crew has the best visual advantage for observing activities like solar array or antenna deployments. If time-critical commanding is to be performed from the AFD, the proper telemetry parameters should be provided for verification. Significant command traffic is best accomplished by the payload operations control center (POCC). Control of POCC-generated hazardous commands to their payload, whether transmitted through the Orbiter system or directly to the payload via ground site, must follow the SSP guidelines set forth in Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), NSTS 1700.7 (current issue) and in POCC Capabilities Document Payload Support Capabilities Description: MCC, JSC POCC, Remote POCC Interface, NSTS 21063. As a backup for loss of the POCC-to-Johnson Space Center (JSC) command capability, the Mission Control Center-Houston (MCC-H) can store important commands in the Generic Command Server (GCS).

Deployment and Separation

5

Payload deployment is that phase of a flight when the payload is released from the Orbiter by some means (RMS, spring ejection system, etc.) and a separation rate is induced to ensure a continually opening rate. The separation rate may be the result of a payload ejection system, an Orbiter translation, or a combination. The net result is that the Orbiter leaves the vicinity of the payload and does not remain to conduct proximity operations.

For more information on payload deployment and separation, refer to System Description and Design Data - Payload Deployment and Retrieval System, NSTS 07700, Volume XIV, Appendix 8. Mission timeline deployment constraints are documented in NSTS 37326. Orbiter control system, visibility, and separation requirements are documented in Space Shuttle Operational Flight Design Standard Groundrules and Constraints, NSTS 21075. Payload deployment constraints on the Orbiter (for example, right-ascension-of-ascending-node (RAAN) and lighting constraints) are specified in IP Annex 2, Part III. All of these constraints are used to compute the launch window as well as to determine deployment opportunities (for example, longitude bands).

Airborne support equipment (ASE) left behind by a deployable payload must be compatible with Orbiter thermal constraints. See System Description and Design Data - Thermal, NSTS 07700, Volume XIV, Appendix 2.

5.1 Deployment Systems

Payload deployment systems are generally of two types: release and ejection. Each has a unique set of requirements.

5.1.1 Release Systems

A release system is one which moves the payload to a desired position relative to the Orbiter and releases the payload. The Orbiter then performs one or more translation maneuvers to produce a

positive separation rate. Release is generally non-impulsive and results in two stable free-flying bodies; therefore, use of a release system relies on the Orbiter to effect any required separation rates necessary to meet payload/Orbiter requirements. The RMS and the stabilized payload deployment system (SPDS) are two such systems.

5.1.2 Ejection Systems

An ejection system is equipped with a self-contained mechanism (usually spring) which furnishes sufficient energy to effect an opening rate between the payload and Orbiter of at least one foot per second (fps). Larger separation rates may be produced by the ejection systems or augmented by an Orbiter translation burn, if required.

The total separation rate (ejection plus Orbiter translation) will be determined by payload requirements and Orbiter operational requirements.

5.2 Attitude and Pointing

The attitude of the Orbiter at payload deployment is a function of payload requirements and Orbiter operations procedures. Payload pointing requirements are most compatible with Orbiter operational requirements if they allow the Orbiter to be in a +ZVV (Orbiter belly along the positive velocity vector) attitude at deployment. Deployment in a direction other than +ZVV may result in a more complicated separation procedure and could increase the potential level of contamination and disturbance due to Orbiter thruster activity; however, other deploy attitudes are acceptable.

Release in either inertial or local vertical/local horizontal (LVLH) is generally acceptable. An LVLH release generally provides a greater deploy window opportunity. Payloads with small

clearances from other structures will be analyzed on an individual basis; release in an inertial attitude hold to maximize clearance may be required.

Another payload concern during deployment is the accuracy with which the payload can be pointed. Several sources of misalignment must be taken into account such as:

- Orbiter inertial measurement unit (IMU) misalignment,
- Orbiter digital automatic pilot (DAP) deadbands, and
- Deployment system misalignment and pointing accuracies.

Despite these sources of error, RMS deploys can generally meet pointing accuracies within 5 degrees of the desired attitude, and ejection type deploys, within 1 degree.

5.3 Tip-Off Rates

The customer should design the payload to be compatible with tip-off rates which might be experienced during deployment. These rates come from such sources as:

- Orbiter DAP deadbands - The payload should be compatible with primary as well as vernier reaction control system (RCS).
- Deployment system - The payload should be compatible with tip-off rates for both nominal and off-nominal deployment.

The payload attitude control system (ACS) should be capable of overcoming these induced tip-off rates, and should be capable of reorienting to its desired attitude after achieving a safe separation distance.

5.4 Appendage Deployment

Some payloads have appendages (solar arrays, antennas, etc.) which must be deployed at or near payload release. The longer a payload can delay appendage deployment during the separation, the less Orbiter thruster plume impingement will affect the stability of the payload and the contamination of its appendage surfaces. Payloads which are

ejected from the Orbiter generally must delay appendage deployment until separated some distance; hence, they avoid the increased impingement effects.

There is a trade-off for payloads released by RMS-type systems, however. The payload can deploy appendages while on the release system and accomplish much of its payload checkout while captured by the Orbiter. Malfunctions may be easier to accommodate in this way; however, the price is increased impingement and increased design loads due to the larger surface areas at separation. Refer to NSTS 07700, Volume XIV, Appendix 8.

Operation of any appendage whose failure to deploy would result in the Space Shuttle taking contingency measures should be designed to be performed while the vehicle is grappled. The primary advantages of operating this way are that

- 1) the RMS is available to point the payload, and
- 2) rendezvous and re-grapple, which are very Orbiter propellant consumptive and which risk higher contamination of the payload by Orbiter jet firings, can be avoided.

Manual appendage deployment by unscheduled extravehicular activity (EVA) is possible but is not a preferred backup for failed appendage deployment operations. Customers requiring an unscheduled EVA capability must design their operations to be compatible with the constraints placed on payload-related EVA. (Refer to System Description and Design Data - Extravehicular Activities, NSTS 07700, Volume XIV, Appendix 7.)

5.5 Payload Attitude Control System-On Times

5.5.1 Hot Gas ACS

Impingement of payload thrusters on the Orbiter are also of concern. The plumes can disturb or contaminate the Orbiter depending on propellant used, thruster size, and separation range. Unlike the payload, however, the major consideration for the Orbiter is disturbance. Generally, if the range is sufficient to satisfy Orbiter stability, then contamination levels are usually acceptable. Plots are available in NSTS 1700.7, that define the

separation range required before the payload is allowed to continue removing “engine arm” inhibits below a safe level. These curves are based on the payload plume torques potentially saturating the Orbiter’s vernier RCS ACS. Either the ejection system, Orbiter translation, or both must be used to achieve the safe distance. Some payloads will have a time limit in which to achieve a safe distance. This limit, in turn, helps define the procedure necessary for separation activities.

5.5.2 Cold Gas ACS

Arming of cold gas thrusters generally follows the same groundrules as the arming of hot gas systems. However, the cold gas thrust magnitude is normally small enough so that the systems can be activated immediately following release. Cold gas ACS will be assessed on a payload-by-payload basis.

5.5.3 Momentum Systems

Some payloads utilize momentum systems to maintain attitude control. They may be used as the primary systems or in conjunction with gas systems. In either case, momentum systems can generally be activated prior to release depending on momentum system size and deployment system capability.

5.6 Payload Gas Translation Systems

Activating thruster systems in the payload which can produce translation by expelling gases (hot or cold) follow the same rules as the previously discussed ACS. Intentional payload translations in close proximity are usually not allowed (excluding release by ejection).

Requirements for solid rocket motor (SRM) arming times are discussed in a following section.

5.7 Plume Impingement

Plume impingement on the payload due to Orbiter jet activity during the separation phase can be a major payload concern. Impingement concerns are centered around disturbance of the payload due to plume forces, and contamination due to deposition of Orbiter combustion products.

5.7.1 Disturbance

During deployment and separation activities, the payload ACS (except for some momentum systems) is inactive until the Orbiter has reached a safe distance. Therefore, during this phase, the payload may be very susceptible to plume impingement forces which could result in upsetting torques. In an effort to minimize these effects, there are several options available to preclude jet activity or to direct the plume away from the payload as much as possible.

The first option considers placement of the payload over the payload bay in such a position as to shadow the payload with parts of the Orbiter structure. Of course, this greatly depends on payload geometry and deployment system capabilities.

A second option would be to perform the separation burn, if required, with the Orbiter in the low-Z DAP mode which directs the plumes farther forward and aft of the Orbiter than the standard Norm-Z mode. (See Figures 5-1 and 5-2.) Although greatly reducing impingement, this option is not always desirable due to the excessive amount of propellant required over the norm-Z mode. This option’s feasibility would be assessed on a payload-by-payload basis.

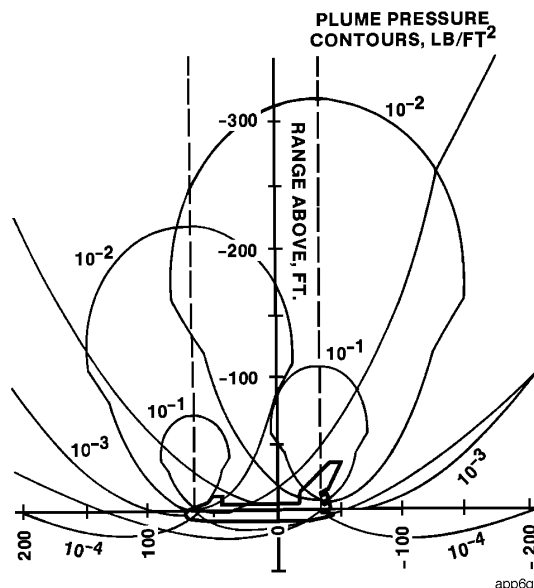


Figure 5-1.- Norm-Z plume contours.

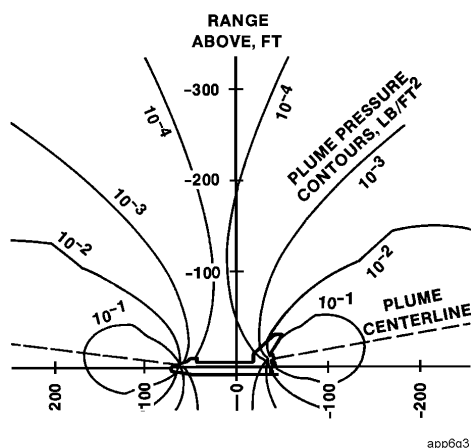


Figure 5-2.- Low-Z plume contours.

A third option would require the separation burn and coast be done with the Orbiter ACS in free drift. This prohibits the ACS thruster from firing, thus deleting that contribution to plume impingement. However, this option would generally require the separation burn be performed in the norm-Z mode to minimize the effects of translation maneuvers evolving into unwanted Orbiter attitude excursions. In either case, the attitude thrusters have to be fired eventually to ensure that the payload remains in view of the crewmember.

These options for reducing disturbance are generally for payload release systems with no separation rate, or for ejection systems imparting small translational impulses. For ejection systems of sufficient size, an additional separation burn may not be required for some time, if at all. However, attitude corrections may be required to maintain the payload in the field of view.

5.7.2 Contamination

Orbiter thruster firings in the vicinity of a payload that result in plume impingement will cause exhaust products to be deposited on the impinged surfaces. These contaminants can be detrimental to payload operations, depending on the level of contamination and the sensitivity of the contaminated surface. The same options available for the reduction of plume disturbance also reduce contamination.

5.8 SRM Firings

Some payloads use an SRM to boost to a higher orbit. SRM's burn a solid fuel containing aluminum which is expelled in the exhaust in the form of aluminum oxide (AlO_2) at speeds of up to 11,000 feet per second. These particles are very abrasive to any surface they strike. Consistent with safe operations, the Orbiter is behind the SRM at ignition and, hence, is impinged upon by the AlO_2 particles. Damage is controlled by establishing a particular SRM/Orbiter geometry at SRM ignition: a combination of trailing range and radial range displacement. The damage can be further controlled by selecting the Orbiter attitude relative to approaching particles.

Since the displacement requirement differs drastically from one SRM type to another, each type calls for a different separation sequence which generally differs only in Orbiter separation burn velocity and direction.

5.9 Ku-band Radiation Levels

Following payload deployment, the Ku-band antenna may be used in the rendezvous radar mode to track the payload and to determine the opening rate that has been achieved. If used, there is an induced radiation level on the payload which is a function of power setting and inter-vehicular range. The customer should design the payload to be compatible with the Ku-band environments described in Shuttle Orbiter/Cargo Standard Interfaces, ICD 2-19001.

The SSP factors the payload's radiation tolerance levels into the separation activities to determine safe ranges and Ku-band activation times. The Ku-band antenna has three power settings which can be selected for various operations. By selecting the proper setting, the crew can minimize the radiation experienced by the payload.

5.10 Payload Visibility

To ensure that a payload is safely separating from the Orbiter at an acceptable rate following deployment, the crew must be able to visually monitor its progress. At a minimum, the crewmember requires the payload to remain within visual acquisition until the separation range exceeds 200 feet. (Out to 1000 feet is preferable.)

Therefore, it is very desirable to deploy in daylight with sufficient light remaining to achieve this requirement. Should the payload require a night deployment, the payload must use Orbiter lighting or payload running lights to provide visibility.

Rendezvous Mission Techniques

6

Rendezvous flights can be divided into two categories: ground-up rendezvous, where the payload is already on orbit at Space Shuttle launch, and deploy-retrieve, where the payload is deployed and retrieved on the same mission. Payloads which require the full, undivided resources of the SSP will probably require a dedicated flight. Rendezvous flight design on a dedicated mission is tailored to the needs of that particular spacecraft and may include many of the techniques mentioned in this section. However, a more desirable method to utilize the SSP is to accomplish the rendezvous on a shared cargo mission. This complicates the flight design somewhat due to the need to meet the rendezvous and shared cargo constraints. The desire to minimize the impact of including a rendezvous on a shared cargo flight led to the development of the standard retrieval policy. This policy defines different classes of payloads depending on their capabilities and mission desires.

Ground-up rendezvous options for shared cargo flights can generally be split into two payload classes: active and passive. Each class has certain characteristics which provide differing amounts of launch window, manifesting opportunities, and flight design flexibility. Payloads which fall under neither class are termed limited active and provide varying amounts of flexibility depending on the payload.

Payloads which have active rendezvous capability are described by the following characteristics:

- 1) large altitude change capability in a period of hours,
- 2) fairly sophisticated guidance and targeting scheme, and
- 3) very accurate navigation requirements using either Global Positioning System (GPS), TDRS, or multiple ground stations.

These spacecraft maneuver both before and after Space Shuttle launch, and provide the Space Shuttle with a large launch window on every day of the launch period for a relatively small on-orbit propellant cost. The rendezvous flight design for these payloads is standardized through the use of the control box technique.

Payloads which have passive rendezvous capability are characterized by their lack of translational maneuvering capability. This class of payloads provides the Space Shuttle with generally smaller rendezvous launch windows at a high on-orbit propellant cost. They have no capability to alter their altitude or orbital plane either before or after launch. The rendezvous flight design for these payloads is mission specific using fairly standard techniques.

Payloads which have some capability to alter their altitude and/or RAAN profile fall under the heading of limited active. This group is not really a payload class but covers vehicles from the nearly active to the nearly passive. The rendezvous flight design is very payload/mission-specific and may include techniques unique to that vehicle. The amount of Space Shuttle on-orbit propellant cost and rendezvous launch window provided is also mission unique.

Payloads which do not require long stays on orbit can use the deploy-retrieve rendezvous option. The payload is deployed and retrieved on the same flight, with a free flight time of a few hours up to several Space Shuttle crew days. This class, in general, has few launch window constraints and no linkages to a deploy flight like the ground-up rendezvous payloads. The flight design is very specific depending on the customer's mission objectives.

Proximity operations are independent of the type of rendezvous technique used and are described in section 8.

6.1 Active Payloads

For active, maneuvering, target spacecraft, the target will usually perform most of the phasing necessary to meet the launch window requirements of the Space Shuttle revisit flight. This technique defines an area in space into which the target descends called the control box. The control box technique minimizes the propellant and time the Space Shuttle needs to commit to the rendezvous. During the first couple of crew days after launch, the target descends into the control box. The Space Shuttle completes the rendezvous once the target has finished maneuvering.

6.1.1 Sequence of Events

The flight design event sequence starts prior to SSP manifesting and flight planning when the payload supplies the SSP with two expected delta-RAAN profiles from deployment or revisit through the next revisit period. These two profiles correspond to the highest and lowest operating altitude profiles that the payload can fly. A candidate deploy or revisit flight, and the next revisit flight, are then evaluated for the payload. These flights must be compatible with shared cargo for Space Shuttle payload bay volume, weight, and center-of-gravity (c.g.) constraints. The revisit flight shared cargo must be compatible with target RAAN and the revisit flight launch date must meet the deploy/revisit flight spacing. The first flight is then launched and payload operations are completed.

Shortly after deploy or revisit, the SSP supplies the customer with the RAAN, date, and time of the next revisit flight nominal launch. The target spacecraft ascends to operational altitude and begins its mission. Thirty days before the revisit launch, an updated date and time are provided along with the down-range position of the control box origin. The target maneuvers to set up the specified plane and down-range geometry required at the nominal Space Shuttle launch time. This is usually done by maneuvering into a 15-revolution groundtrack-repeating orbit at approximately 257 nmi altitude several weeks before launch. A couple of days before launch, the payload ceases all translational maneuvering, and the SSP tracks the target and launches the Space Shuttle into the target's plane.

Once on orbit, the Space Shuttle gives the target a go-for-descent after post-ascent checkout. During the next few crew days, the target spacecraft descends into the control box and ceases all translational maneuvering. During this period, the two vehicles are operating autonomously, with the Space Shuttle satisfying the needs of its shared cargo and coasting towards the control box origin, and with the target spacecraft maneuvering to get into the control box. After both spacecraft satisfy their desired conditions at control box start time, the SSP tracks the target and completes the rendezvous on the following crew day.

6.1.2 Spacecraft Operational Orbit

The spacecraft must be deployed in an orbit compatible with retrieval from the control box in a 28.45-degree inclination. If the spacecraft is deployed by the Space Shuttle, it will nominally be in the standard orbit described in section 2. This is because a large number of customers utilize the standard orbit, making manifesting and flight design easier. The actual deploy altitude will be decided on a mission-specific basis. Spacecraft flexibility is desired to allow manifesting with another payload which may be going to an altitude higher or lower than that of the standard orbit. Most spacecraft will probably boost to a higher operational altitude (typically 240 to 300 nmi) and descend back to the control box for retrieval. This higher altitude provides adequate orbit lifetime and also provides the required phasing rates to accommodate a one hour launch window for the revisit flight.

6.1.3 Spacecraft Maneuver and Targeting Requirements

One of the major requirements on the target spacecraft's maneuvering systems is to have the capability of flying different operational altitude profiles in order to provide the SSP with deploy slip or retrieval launch day flexibility. The requirements for a particular mission fall into three categories depending on the nature of the customer's payload:

- customers using Space Shuttle deployment,
- customers using other means to deploy, and
- customers needing Space Shuttle revisits.

A customer using Space Shuttle deployment should provide the SSP two predicted RAAN profiles which correspond to the high and low operating altitude profiles of the customer's spacecraft. The predicted RAAN profiles should diverge by at least 0.2 degrees per day. These data should be delivered to the SSP before the planning starts for the deploy flight. This requirement allows the rendezvous-flight RAAN to remain constant when the deploy-flight launch slips. For a deploy/revisit flight pair that is 225 days apart, this RAAN-altering capability would provide for a 45-degree change in deployment RAAN which corresponds to about a 3-hour deploy launch slip on the best day. The SSP will take the high-altitude predicted RAAN profile line and pick a deploy/revisit flight pair which corresponds to this line. Then, as the deployment RAAN increases due to launch slips, the customer's spacecraft will need to fly lower to meet the specified revisit-flight RAAN.

Customers not using the Space Shuttle to deploy their spacecraft should provide the SSP with a predicted RAAN profile which represents the operating altitude best suited for a nominal flight. These data should be delivered to the SSP prior to negotiations leading to a rendezvous flight selection. The rendezvous-flight RAAN will then be negotiated considering these RAAN data, possible Space Shuttle rendezvous flights, and the customer's launch constraints. Once the rendezvous-flight RAAN is agreed upon, the customer is responsible for managing the deploy-launch-slip/payload-operating-altitude tradeoffs. The underlying requirement is meeting the rendezvous-flight RAAN in both the nominal and off-nominal scenarios.

Customers needing a revisit to a spacecraft should provide the SSP with two predicted RAAN profiles which correspond to the high and low operating altitudes of the customer's spacecraft. The RAAN history profiles should diverge by at least 0.2 degrees per day. These data should be delivered to the SSP before the planning starts for the revisit flight. The SSP uses this RAAN flexibility by picking a revisit flight somewhere in the achievable RAAN range. The 0.2-degree-per-day variance is highly desired but open to negotiation. The greater the customer's capability, the easier it is to manifest the rendezvous flight.

Around the time of the deploy or previous revisit flight, the SSP will specify a revisit flight RAAN that the spacecraft must achieve at the nominal Space Shuttle revisit flight liftoff time. The target vehicle must achieve this specified RAAN within 1.0 degree. This revisit flight RAAN will be selected such that it falls within the bounds defined by the two predicted delta-RAAN profiles provided by the customer for vehicles using a Space Shuttle deploy or revisit flight. The spacecraft is responsible for compensating for deviations caused by atmospheric drag uncertainties over its mission.

The control box origin at control box start time will be specified by the SSP as a point in a particular circular orbit at a specified Space Shuttle mission elapsed time (MET). This requires the spacecraft to adjust both its plane and down-range position in relation to this point and allows the SSP to complete rendezvous within the restrictions of time, maneuver capability, and launch opportunity imposed by typical shared cargo retrieval flights.

The targets for the spacecraft revisit will be provided at three times. Initial targets are provided shortly after deployment to define plane orientation, date, and time of the nominal Space Shuttle revisit flight launch. The updated targets are provided at least 30 days prior to the revisit-flight launch to define plane orientation, date, and time of the nominal Space Shuttle revisit-flight launch. Also provided are control box start time, go-for-descent, and the control box origin (argument of latitude) in the orbit plane. The final targets are given shortly after the revisit flight launch to define the final plane orientation, the control box origin's argument of latitude, the control box origin's semi-major axis, and the control box start time in GMT. These final targets will include adjustments of up to 0.1 degrees in orbital plane (inclination and RAAN), 5.0 degrees in the control box origin's argument of latitude, and 1.0 nmi in the semi-major axis of the control box origin.

The date and time of revisit for the initial and updated targets refer to the nominal Space Shuttle revisit flight launch time and are stated in GMT. The date and time of revisit for the final targets refer to control box start time. This time will be stated as a nominal lift-off time in GMT plus a control box start time relative to lift-off time in Space Shuttle MET. For Space Shuttle launch

delays, the lift-off time will change but the Space Shuttle MET of control box start time will remain constant.

6.1.4 Control Box

The region into which the target spacecraft must maneuver by the start of the Space Shuttle rendezvous phase is called the control box. The control box levies accuracies on the target's position relative to the Orbiter at control box start time. The phase and energy constraints are shown in Figure 6-1. In addition, the target plane, which is defined by inclination and RAAN, must be accomplished within 0.03 degrees. The eccentricity (apogee minus perigee) should be no more than 8.0 nmi. The target vehicle must satisfy all the constraints, energy, phase, plane, and eccentricity, at control box start time, to be considered in the control box.

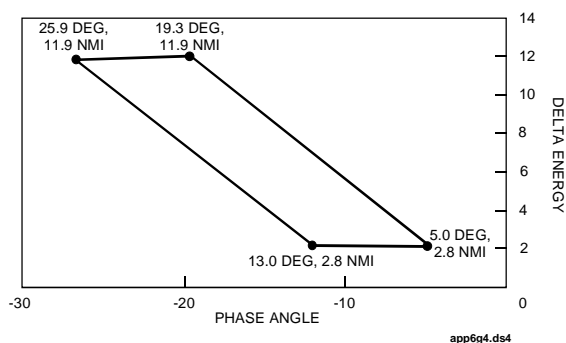


Figure 6-1.- Control box at 2 days 1 hour MET.

6.1.5 Revisit Flight Launch Window

The revisit launch window is determined by a combination of Space Shuttle ascent yaw steering and target vehicle phasing capability. The Space Shuttle will provide the planar portion of the launch window through its ability to yaw steer during ascent. Typically, a 60-minute planar window is provided using 1000 lb of ascent yaw steering. The actual value available for yaw steering is flight-specific.

The target spacecraft should provide a 60-minute continuous phase window which is coincident with the Space Shuttle-provided planar window. This phasing capability is related to the launch slip because the payload moves down-range at approximately 4 degrees per minute during the launch slip. Therefore, to cover a 60-minute slip,

the target should be able to handle an initial phase angle which varies up to 240 degrees. The initial phase angle will also vary from day to day unless the target is in a 15-revolution ground-track-repeating orbit at approximately 257 nmi. The target spacecraft must have enough phasing capability so that it doesn't shorten the overall launch window. This 60-minute phase window can be accomplished in two ways.

The target could be in a 15-revolution ground-track-repeating orbit (at approximately 257 nmi altitude) and have a phasing capability of 240 degrees. This method also requires maneuvering to a particular phase angle with respect to the Space Shuttle at the nominal launch time. In maneuvering to attain this particular phase angle at the nominal launch time, the target spacecraft should be aware that a given RAAN and phase cannot be reached by just in-plane maneuvers. That is the reason that the target spacecraft only has to hit the specified RAAN target within 1 degree. Overcoming the RAAN/phase interlock to hit the RAAN and phase targets exactly would otherwise require approximately 0.5 degrees of RAAN change in the worst case.

The other possibility is that the target must have enough phasing capability to provide 240 degrees of continuous phase window regardless of its phase angle position at Space Shuttle launch. This method might be used by spacecraft which have an operating altitude in excess of 300 nmi and which do not want to come down to 257 nmi prior to Space Shuttle launch. The target spacecraft must have enough propellant to reach the phasing orbits required by this technique.

6.1.6 Revisit Flight On-Orbit Timeline

A go-for-descent will be given to the retrieval customer within the first few hours after a successful Space Shuttle launch (nominally at 5 hours Space Shuttle MET). This signifies that the Space Shuttle is ready for nominal on-orbit operations and the target spacecraft is free to begin its descent into the control box. This ensures that the Space Shuttle is successfully on orbit and operational before committing the customer to maneuver the spacecraft to the retrieval orbit, maximizing the probability of a successful retrieval before any target spacecraft propellant is expended.

The target spacecraft then maneuvers into the proper phasing orbits prior to descending into the control box. The spacecraft must be in the control box and stop all translational maneuvering at the control box start time, a minimum of 40 hours after go-for-descent is given. The 40-hour interval minimizes the mission impact of including a control box rendezvous on the flight, allowing the first two Space Shuttle flight days to be dedicated to shared cargo operations.

The spacecraft must be capable of achieving a safe retrieval-ready mode prior to grapple. This includes having an acceptable value for Orbiter/spacecraft differential drag. After rendezvous and grapple, up to three hours will be dedicated to payload berthing/support. The subsequent crew work period may be purchased as an optional service for additional time.

6.1.7 Target Spacecraft Tracking Requirements

Accurate target spacecraft tracking is critical for the successful completion of the rendezvous. Therefore, the target vehicle tracking responsibility is given to the active vehicle. The target spacecraft must complete its RAAN and phase adjustment maneuvers prior to the Space Shuttle prelaunch targeting and is responsible for the tracking during this phase. During Space Shuttle pre-launch activities, the SSP will track the target to determine an accurate target plane for which to aim during ascent. During the target spacecraft's descent into the control box, the customer is responsible for the tracking necessary to execute its maneuvers and to get it into the control box. After the target completes its descent into the control box, the Space Shuttle will track the target spacecraft through the completion of the rendezvous. The target vehicle must complete its maneuvering into the control box by control box start time to allow for enough time for SSP tracking to begin the Space Shuttle portion of the rendezvous.

6.1.8 Active Payload Summary

The spacecraft should be deployed in an orbit compatible with retrieval from the control box at 28.45-degree inclination. The payload spacecraft will probably boost higher to achieve its operational orbit (typically 240 to 300 nmi). One retrieval opportunity will be provided during a 90-day

interval beginning no earlier than six months after deployment. The target spacecraft's deboost to retrieval orbit will begin after Space Shuttle launch for the retrieval flight when the Orbiter systems are verified operational for retrieval. The descent to the retrieval orbit should be completed within 40 hours after go-for-descent is given. The spacecraft will provide control of position in the orbital plane (phase angle) to facilitate a 60-minute launch window and will provide limited orbit plane orientation control. The target spacecraft tracking is the responsibility of the active vehicle's organization.

6.2 Passive Payloads

The standard retrieval policy for passive spacecraft desiring shared cargo revisit, reboost, deploy/retrieve, or retrieval services covers the following general items. The revisit is to an orbit with compatible Space Shuttle inclination and altitude, and deploy plans should be compatible with this orbit. The Space Shuttle performs all the maneuvers necessary to complete the rendezvous.

6.2.1 Sequence of Events

For payloads not retrieved on the deploy flight, the payload supplies the SSP with the expected delta-RAAN profile from deployment through the revisit period prior to Space Shuttle manifesting and flight planning. Candidate deploy and revisit flights are then evaluated for the payload. The deploy flight is chosen so that it is compatible with the shared cargo for Space Shuttle payload bay volume, weight, and c.g. constraints. The revisit-flight shared cargo must be compatible with the projected target RAAN. The revisit flight must also meet the agreed deploy/revisit flight spacing.

The deploy flight is launched and the payload is deployed. Shortly after deployment, the SSP supplies the customer with the date and time of the revisit flight nominal launch. The target spacecraft then begins its mission. The SSP will keep the customer informed of any changes in the retrieval flight launch plans. The SSP tracks the target and launches into its plane. The SSP tracks the target and completes the rendezvous.

6.2.2 Spacecraft Operational Orbit

The deployment should be in an orbit compatible with Space Shuttle operational attitudes.

6.2.3 Deployment-to-Revisit Time Interval

In most cases the deploy and retrieval occur on the same flight with deployed operations covering one crew day up to approximately 13 days (STS-80). The length of deployed operations can be negotiated. Revisit flights or consecutive revisit flights, may be co-designed because they must be manifested as a pair for customers desiring a short flight-to-flight interval. The linkage between the flights is decreased by increasing the time between them. This interval is constrained in order to limit the necessity of developing retrieval flight data prior to the successful completion of the deploy flight. This allows the retrieval flight to be modified in case of a failed or anomalous deployment and will minimize the number and scope of Space Shuttle cargo redesign efforts.

The retrieval opportunities can be limited because the Space Shuttle must go to the target plane with compatible shared cargo. Other considerations include the possibility of a nonstandard launch altitude, the need to reboost the payload, and the other payload launch priorities and their orbital requirements.

The deploy flight opportunities, if applicable, may also be limited. The payload spacecraft must meet Space Shuttle payload bay volume, weight, and c.g. requirements for the flight under consideration. A higher than 160-nmi deployment orbit is usually necessary to ensure adequate orbit lifetimes.

One revisit flight will be planned by the SSP to occur during a 90-day interval which begins no earlier than six months after the deploy flight. When retrievals are mixed with the standard launch window for deployable spacecraft, launch opportunities can be significantly limited. The 90-day interval provides a reasonable assurance that the SSP can manifest a mission that has a suitable cargo and launch opportunity.

In the event a retrieval is not accomplished as planned, a retrieval reflight opportunity will be provided. This flight will be consistent with the reflight policy for all SSP customers and be a "best

try" consistent with other priorities. It implies attempting to rendezvous on the nominal revisit at an altitude high enough that the spacecraft is in a safe retrievable altitude (greater than 130 nmi and perhaps higher if the target spacecraft is unable to maintain a stable attitude at low altitudes) for at least nine months following the failed rendezvous.

6.2.4 Revisit Flight On-Orbit Timeline

After Space Shuttle launch, the Orbiter performs the services necessary for the shared cargo. At the same time, the Orbiter performs the necessary rendezvous maneuvers to reach on-board sensor range on the day of rendezvous. The Orbiter then tracks the target spacecraft and completes the rendezvous.

The spacecraft must be capable of achieving a safe retrieval-ready mode prior to grapple. This includes having an acceptable value for Orbiter/spacecraft differential drag. After rendezvous and grapple, up to 3 hours will be dedicated to payload berthing/support.

6.2.5 Target Spacecraft Tracking Requirements

Accurate target tracking is critical for the successful completion of the rendezvous. During Space Shuttle prelaunch activities, the SSP will track the target to determine an accurate target plane for which to aim during ascent. Once on orbit, the Space Shuttle will track the target vehicle through completion of the rendezvous.

6.2.6 Passive Payload Summary

The spacecraft should be deployed in an orbit compatible with a standard orbit described in section 2. The spacecraft should use an initial operational orbit that is compatible with orbit lifetime requirements (typically 200 to 300 nmi). One retrieval opportunity will be provided during a 90-day interval beginning no earlier than six months after deployment.

6.3 Limited Active Payloads

Payloads which have some capability to alter their altitude and/or RAAN profile fall under the heading of limited active. This group is not really a payload

class but covers vehicles from the nearly active to the nearly passive. In order to provide maximum manifesting and flight design flexibility, the SSP encourages customers to make their spacecraft as close to fully active as possible. The rendezvous flight design is very payload/mission-specific and may include techniques unique to that vehicle. The actual requirements for payloads which do not fit either active or passive are worked out on a payload/mission-specific basis. For many of the requirements stated under the active and passive payload sections, some middle ground does exist.

The capabilities that a limited active payload has to support a Space Shuttle rendezvous are directly related to the sophistication of the spacecraft's guidance, navigation, and control (GNC) system and the amount of propellant available for translational maneuvers. To be considered fully active, a spacecraft must provide a number of capabilities:

- a large phase window, usually through the use of a groundtrack-repeating orbit;
- the ability to adjust its down range position, plane, and altitude during the weeks before the launch of the rendezvous mission; and
- the ability to quickly adjust its position and altitude after Space Shuttle launch.

Limited active can be broken down into several subsets of the active requirements.

The most desirable limited active payload is a spacecraft with all of the above capabilities except the ability to reach the 15-revolution groundtrack-repeating orbit. Without the use of this orbit, the initial phase angle will vary from day to day depending on the target orbit. This will result in small launch windows on some days of the launch period. Multiple-day groundtrack-repeating orbits exist at approximately 175 nmi (29 revs, every other day) and 202 nmi (46 revs, every third day), which may be used to enhance the overall launch period situation. Payloads which fall under this group provide the same low rendezvous propellant cost for the Space Shuttle as the active group but lack the one-hour daily launch window.

The next level of capabilities is represented by spacecraft which have the ability to alter down-range position, plane, and altitude before the

rendezvous launch, but are unable to maneuver quickly after launch. This means that the target spacecraft remains passive after launch and the Space Shuttle has to perform all of the post-launch rendezvous maneuvers. This provides small daily launch windows and, depending on the target altitude, could cost the Space Shuttle more propellant to complete the rendezvous.

Spacecraft with a smaller amount of capability than this may only be able to affect their position and altitude and have little if any plane-altering ability. A spacecraft in this group limits the flexibility of its deploy flight launch window or, if already deployed, the flexibility of its revisit flight launch day. Like the previous group, the daily launch windows are small and the Space Shuttle propellant cost may be higher than the active class.

A payload spacecraft with only the smallest amount of maneuvering capability is only able to change its down range position at launch with little altitude or plane change capability. The only advantage this has over a passive payload is it allows the nominal launch day window to be aligned as desired.

The sequence of events for limited active payloads is highly dependent on the payload's maneuvering capability. For payloads which are passive after Space Shuttle launch, the only event which affects the payload is the rendezvous. For payloads using the control box technique, the full definition of important timeline events is given in the active payloads section.

6.4 Deploy-Retrieve

The standard retrieval policy for deploy-retrieve target spacecraft desiring shared cargo services consists of two basic guidelines. The deployment and retrieval are from the standard orbit described in section 2. The interval between deployment and retrieval could be up to four Space Shuttle crew days and is usually constrained by crew sleep periods. Additional on-orbit days may be added as a nonstandard service

6.4.1 Sequence of Events

The payload is checked out and deployed, and the Space Shuttle performs separation maneuvers to back away from the payload. The payload

spacecraft begins its mission which may or may not involve the Space Shuttle. Subsequently, the Space Shuttle tracks the target and completes the rendezvous.

6.4.2 Operational Orbit

The deployment will be from a standard orbit as described in section 2. This is because a large number of customers utilize the standard 160-nmi orbit, making manifesting and flight design easier. Requiring an increased orbit altitude and inclination reduces Space Shuttle launch weight capacity. However, spacecraft flexibility is desired to allow manifesting with another payload which may be going to an altitude higher or lower than 160 nmi.

6.4.3 Deployment-to-Retrieval Time Interval

The interval between deployment and retrieval could be up to four crew days. Additional on-orbit days may be added on a nonstandard service.

6.4.4 On-Orbit Timeline

The spacecraft must be capable of achieving a safe retrieval-ready mode prior to grapple. This includes having an acceptable value for Orbiter/spacecraft differential drag. After rendezvous and grapple, up to 3 hours will be dedicated to payload berthing/support. The subsequent crew work period may be purchased as an optional service for additional time.

6.4.5 Target Spacecraft Tracking Requirements

Accurate target tracking is critical for the successful completion of the rendezvous. The SSP will track the target vehicle throughout the free flying phase of the deploy-retrieve spacecraft.

6.4.6 Deploy-Retrieve Payload Summary

The deployment and retrieval are from the standard orbit as described in section 2. The free-flying interval may be as long as four crew days. Additional on-orbit days may be added as a nonstandard service.

Rendezvous Operations

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A rendezvous involves a multi-orbit, multi-impulse maneuver sequence ending in a manual approach phase. (See section 8.1, Proximity Operations Phases.) The Space Shuttle rendezvous operations which affect the payload involve the use of the Space Shuttle on-board sensors. The rendezvous radar is also discussed in section 8.3, along with other Space Shuttle on-board sensors.

mission success for radar lock-on to occur as soon as possible after the range has closed to within 27 nmi. For radar lock-on at 27 nmi, the effective radar cross section needs to be approximately 53 square meters.

7.1 Star Tracker Rendezvous Navigation

To support required star tracker rendezvous navigation, the payload must be capable of being tracked by the Orbiter to a range of 250 nmi from orbital noon to orbital sunset. This requirement can be satisfied by providing payload surface reflectivity characteristics and an attitude timeline that allow continuous payload visibility to the Orbiter star tracker in reflected sunlight (equivalent brightness of a third magnitude star) for a minimum of 30 minutes per orbit revolution. Failure to meet this long-range tracking requirement will result in specialized mission planning with attendant delta costs and/or degraded probability of mission success.

7.2 Radar Rendezvous Navigation

Radar rendezvous navigation requires a payload to have an attitude-independent effective radar cross section of at least 1.0 square meter. This allows the rendezvous radar to assure lock-on to the payload outside a range of 10 nmi and to remain locked on until a range of 100 feet. Payloads with an effective cross section of less than 1.0 square meter are incompatible with current rendezvous techniques. The radar is capable of updating navigation data while the payload is within 27 nmi, provided radar lock-on has occurred. It is beneficial in terms of controlling trajectory dispersions and increasing the probability of

Proximity Operations

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Proximity operations are flight operations during which active man-in-the-loop trajectory management tasks are conducted in the vicinity of a free-flying target. They are most often post-rendezvous activities, but they can also be post-deployment activities (for example, inspection flyaround). During proximity operations, the relative position and rates are sufficiently small and stable (less than 0.5 nautical mile and less than 1.0 feet per second) so as to preclude the requirements for rendezvous activities (with all attendant navigation targeting and Orbiter maneuvers) to restore proximity. Post-rendezvous proximity operations can include final approach to, flyarounds of, stationkeeping with, and capture/dock of a payload. In addition to these operations, post-deploy proximity operations will include an Orbiter separation maneuver designed to keep the Orbiter within proximity. The flying techniques used during proximity operations are manual and as such are highly crew-intensive. During proximity operations, through-the-window visual acquisition is required.

8.1 Proximity Operations Phases

8.1.1 Approaches

The approach to a free-flying target begins in the manual or terminal phase of the rendezvous. This phase serves as a transition between rendezvous operations and proximity operations. It is designed to bring the Orbiter from a position below and slightly behind the target (LVLH coordinates) at a range of 2,000 feet to a stable position close to the payload (on the target's +RBAR) at a range of about 6400 feet. The final approach starts from this position. There are several accepted techniques to perform a final approach, and one is chosen based on the payload's attitude, attitude control system, geometry, and sensitivity to the Orbiter's RCS plume overpressure. The final approach brings the Orbiter to within a distance of about 35 feet from the payload where a final

braking maneuver is performed and the payload can be captured by the RMS.

8.1.2 Final Approach Techniques

The Orbiter is capable of an approach for close-in stationkeeping with and/or RMS grapple of a payload stabilized in either a LVLH reference frame or in an inertial reference frame. Standard approaches have been defined to a target stabilized in either frame with a grapple fixture positioned within the RMS reach limit. Any other stabilization scheme or grapple fixture orientation must be considered on a case-by-case basis.

The preferred final approach method is the LVLH +RBAR approach. From a position 6400 feet below the payload, the Orbiter approaches along the payload's positive radius vector or +RBAR to within 35 feet of the target. This approach is preferred because it uses only a small amount of Orbiter propellant and offers the least plume impingement on the payload. Approaches along other LVLH directions (+VBAR, -RBAR, etc.) can also be used. The Orbiter first performs a flyaround to that approach axis and then comes in as before.

The inertial approach is often used for inertially stabilized payloads. The standard procedure is for the Orbiter to approach to as close as possible range on the payload's +RBAR and stationkeep there until relative rotation of the target presents an optimum orientation. The Orbiter then selects inertial attitude hold, and the Orbiter approach is completed to 35 feet along the inertial line of sight. This approach is generally only slightly more propellant expensive than the +RBAR approach.

8.1.3 Stationkeeping

During proximity operations stationkeeping, the Orbiter maintains a constant position relative to the target. One type of stationkeeping is performed at very close ranges (35 feet) to allow the RMS to grapple the payload. Another form of

stationkeeping is performed at longer ranges (100 to 2000 feet). It allows the Orbiter to “stand by” close to the payload to assist in payload communication and/or viewing during extended periods of payload checkouts. The payload could also be retrieved from this position should that need arise. Long-range stationkeeping is generally performed on the target’s +VBAR.

8.1.4 Flyarounds

During flyarounds, the Orbiter translates around the target in the LVLH frame. This is usually performed to properly orient the payload to facilitate viewing of, approach to, or grapple of the payload. The flyaround can be performed at short ranges (35 feet) or long ranges (up to 5400 feet). Short-range flyarounds are limited to payloads small enough to comfortably avoid a collision danger during the flyarounds. It is highly desirable to keep long-range flyarounds in the target’s orbit plane due to the significantly higher propellant cost of an out-of-plane flyaround.

8.1.5 Proximity Operations Separations

Proximity operations separations are designed to provide some separation between the payload and the Orbiter, but to stay within the proximity operations regime (as defined in section 8.1.3) in order to accomplish payload goals such as communications support. These separations are different from nominal separations in that nominal separations are designed to terminate proximity operations. These separations are usually performed to provide post-deploy inspection/photography. They usually involve stationkeeping or flying around the payload one or more times before final separation.

8.2 General Techniques

In general it is highly desirable to keep all proximity operations trajectories in the plane of the target. This minimizes propellant use and maximizes operational flexibility. It is also highly desirable to maintain an Orbiter attitude that keeps the Orbiter’s X-axis in the orbit plane.

The Orbiter aft crew station overhead window remains pointed at the target during all proximity operations except close-in operations, which occur at ranges of less than 100 feet. During close-in

operations, the Orbiter is maneuvered so that the relative position of the target is near the middle of the payload bay where the target is visible from either the overhead windows or the aft windows.

8.3 Sensors

Several sensors are used by the Orbiter crew during proximity operations to determine relative range and range rate, as well as rates perpendicular to the line of sight. These include rendezvous radar (RR), the Trajectory Control Sensor (TCS), Hand Held Lidar (HHL), the Crew Optical Alignment Sight (COAS), and closed circuit television (CCTV) cameras.

The RR is essential for accurately determining range to the target and range rate. It is used from the beginning of the final approach down to a range of 100 feet where it breaks lock.

The TCS is a laser sensor that provides the same data in proximity operations as the RR. The TCS is more accurate and can provide data into very close range but requires reflectors to be placed on the payload.

The HHL is a hand held laser device that is manually pointed toward the payload and provides range and range rate data. It is generally used as a backup sensor to the RR or TCS.

The COAS is used as an alignment aid for the crew for early detection and correction of rates perpendicular to the line of sight to the target. It is an illuminated sight with a reticle pattern to measure a payload’s angle from the Orbiter’s -Z axis (overhead window). It may also be used as a visual backup aid to determine range by measuring subtended angle and deriving a very rough measure of range rate.

The television cameras are generally used for alignment and piloting cues. They can also be used to determine range by triangulation within 200 feet and, again, offer a rough calculation of range rate.

8.4 Viewing/Visibility Requirements

The payload must be visible during all proximity operations. In addition, the payload shape and orientation must be clearly discernible to the crew at a range of 1000 feet and less. Normally, the proximity operations are designed such that the payload is in sunlight until close range.

If nighttime operations are performed, the following options may be used to help satisfy the visibility requirements:

8.4.1 Use of the Orbiter Docking Light

The Orbiter docking light may be used to illuminate the payload. The SSP can perform studies to determine the adequacy of this lighting for a specific payload. In order to perform these studies, the customer must supply the SSP with the reflectivity characteristics of the payload's surface material.

8.4.2 Use of an Optical 1,000,000-Candlepower Spotlight (Streamlight)

This portable light is brighter than the docking light and can increase the range at which a payload can be illuminated. Since this equipment is optional, it must be manifested for each specific flight. An SSP lighting study can be used to determine if this option is necessary.

8.4.3 Use of Reflectors or Running Lights

Reflectors or payload-mounted running lights can be used to increase the probability and/or range of payload visual acquisition. The customer should check with the SSP for recommendations on number, placement, and characteristics of reflectors.

8.5 Plume Impingement

Due to the nature of the Orbiter activities during proximity operations, it is impossible to completely preclude the impingement of Orbiter thruster exhaust on some surfaces of the payload.

However, some precautions can be exercised which tend to minimize the effects of impingement. One is the use of the +RBAR approach which results in almost no plume impingement. For other operations, the primary reaction control system (PRCS) thrusters can be used, when permissible, for attitude control and translation in the low-Z mode as described in section 5 (Figure 5-2). This mode can be selected depending on the relative geometry at the time of thruster activity.

Impingement on the payload may be of concern for two reasons: the plume exerts forces on the payload that may damage it or disturb its attitude, and the products of combustion may strike the payload's surface and contaminate it.

8.5.1 Disturbance

Exhaust gases from the Orbiter engines may exert significant forces on payload surfaces. As a result, a payload surface could be damaged or the entire payload could be displaced from its desired attitude depending upon the payload's mass properties and the torque impulse exerted on the payload.

8.5.2 Contamination

Another concern for a payload is contamination of sensitive surfaces by Orbiter exhaust products such as water and unburned propellants. In most cases, contamination is not a problem.

8.6 Retrieval Operations

Retrieval operations are a specialized subset of proximity operations. An RMS retrieval occurs as the Orbiter is stationkeeping at a range of 35 feet. The nominal payload orientation relative to the payload LVLH or inertial reference frame must be made known before flight. This is required for retrieval sequence planning. The payload should be in this retrieval attitude prior to the Orbiter's arrival on the payload's +RBAR. (Refer to NSTS 07700, Volume XIV, Appendix 8, for RMS attitude and rate constraints.) How long the payload must maintain this attitude depends upon the time required to perform the planned retrieval and subsequent grapple. At a minimum, it should allow for one aborted approach, an Orbiter backaway and a second approach and grapple attempt. This period should generally not be less than one and a

half hours, and could be more, based on the complexity of the approach and grapple techniques. During final approach, the attitude control system should be active to stabilize the payload until just prior to grapple, at which point it should be deactivated and safed consistent with the requirements in NSTS 1700. This is required to preclude a more costly flyaround by the Orbiter. For the payload to meet the requirements in section 8.8, the grapple fixture locations must be compatible with planned approach techniques.

8.7 Payload Appendage Stowage

Payload appendages such as solar arrays, antennas, etc. not only can make it more difficult for the Orbiter to safely approach to a grapple position, but also can make the payload more sensitive to plume impingement torques from PRCS jet firings during proximity operations. All appendages that would adversely affect the Orbiter's ability to approach and stationkeep with the payload should be stowed prior to the Orbiter's arrival on the +RBAR.

8.8 Payload Attitude Control System (ACS) Activation/Deactivation

The payload ACS must conform to the following:

Hot gas thrusters must be safed at a range dependent on thruster size.

Often, cold gas thrusters and momentum wheels can be left on until just prior to grapple; however, the customer must negotiate these inhibits with the SSP. More information is available in section 5.5 and in NSTS 1700.7.

Rendezvous Ground Navigation Requirements

9

Navigation accuracy to support rendezvous and revisit operations requires Orbiter and target tracking data. Attitude maneuvers prior to the tracking phase will produce trajectory perturbations, and additional tracking is required to obtain a high quality vector. As part of the rendezvous and retrieval services, the SSP will schedule C-band, S-band, remote tracking station (RTS), and/or TDRSS tracking, as appropriate, to satisfy the SSP tracking requirements for the Orbiter and target.

Doppler data for target tracking needs to have coherent onboard frequency turnaround in order to be processed in the MCC-H. The customer will need to provide the target's uplink transmission frequency in IP Annex 2, Part III, and confirm the frequency with the MCC-H Track Controller before the start of the first tracking pass. Ground C-band tracking of a target must have a maximum elevation of at least 10 degrees. Targets with small radar cross-sections may require maximum elevations of at least 30 degrees to ensure adequate tracking data acquisition.

9.1 Critical Tracking Phase

A critical tracking phase is defined to be four orbits preceding a rendezvous maneuver. The timeframe includes three and a half orbits for target tracking and 45 minutes for data processing and uplink. No target translational maneuvers are permitted during the critical tracking phase.

9.1.1 Active Target

Spacecraft with maneuvering systems that produce significant trajectory perturbations are defined as active targets. Target rotational maneuvers and attitude control may produce translational velocity changes that degrade state vector accuracy. Two tracking passes per orbit are required during the critical tracking phase for active targets.

9.1.2 Quiescent Target

Spacecraft with onboard systems that do not produce and significant trajectory perturbations are defined as quiescent targets. One tracking pass per orbit is required during the critical tracking phase for quiescent targets.

9.2 Noncritical Target Tracking Phase

A noncritical target tracking phase is defined as the times when target tracking data is required for orbital maintenance and attitude control evaluation and/or drag evaluation. The tracking density required is an average of one tracking pass every two orbits on the target.

9.3 Orbiter Tracking

The SSP will schedule ground C-band passes in addition to TDRS tracking data to satisfy the navigation accuracy required during rendezvous periods. Two C-band passes per orbit are required during the final rendezvous period prior to target grapple.

9.4 Initial Target State Vector

A target state vector is required two hours prior to the time of the first tracking pass to initialize the orbit determination processor. For control box rendezvous, this vector shall be propagated to the control box start time. The customer shall provide the initial vector as defined in [POCC Capabilities Document](#), NSTS 21063. For control box rendezvous, there are no requirements for the SSP to track the target after the prelaunch tracking period until the control box start time.

9.5 Launch Targeting Vector

For a ground-up and control box rendezvous, the SSP requires prelaunch target tracking from lift-off minus 48 hours (24 hours for known targets) through launch when a launch targeting vector is required. The tracking elevation for targets will be 10 degrees or higher. This tracking is necessary to obtain navigation covariance history and evaluate drag effects. The tracking phases defined for this time period are as follows:

For known targets:

L-24 to L-19 hours	Two tracking pass every orbit on the target
L-19 to launch	one tracking pass every other orbit on the target

For unknown targets:

L-48 to L-43 hours	Two tracking pass every orbit on the target
L-43 to launch	One tracking pass every other orbit on the target

NOTE: No target maneuvering is permitted from launch minus 48 hours to launch.

Orbiter Attitude Control and Pointing Capabilities

10

This section discusses attitudes the Orbiter is capable of maintaining and attitude maneuvers the Orbiter is capable of performing to satisfy payload requirements on orbit. Also presented is information on typical pointing accuracies that may be achieved when using the Orbiter as a pointing platform for payload instruments or Orbiter sensors. If more detailed information on Orbiter attitude control and pointing capabilities is needed, the customer is encouraged to speak with their SSP representative.

10.1 Attitude Control Thrusters

RCS jets are primarily used for Orbiter attitude control and pointing operations. Figure 10-1 shows the location of these jets on the Orbiter and the directions of their thrust vectors.

Two types of jets are available: primaries (PRCS) and verniers (VRCS). Primary jets have two modes, normal PRCS operation and alternate (ALT) mode operations. In Alt mode the DAP can be programmed to fire 1, 2, or 3 PRCS jets at one time and a delay can be inserted between jet firings. This mode is used for attitude control when the vernier jets fail as well as for controllability and propellant saving for certain spacecraft configurations and mass distributions. Normal PRCS is used for small translational burns, coarse attitude control, high attitude maneuvers rates.

Vernier jets provide finer attitude control and are thus usually requested by customers with tight attitude accuracy requirements. Attitude hold is achieved with vernier jets, as are attitude maneuvers that are not time-critical. Maneuver rates or rotation rates that exceed the normal

operating limit of the vernier jets are usually performed by initiating the rate with primaries and then switching to verniers once the rate is established. (See Rotation Attitude Option.) Primaries are then used to stop the rotation or maneuver.

Primary jets have redundancy; the verniers do not. Therefore, if a failure occurs that prevents the use of one or more vernier jets, either the Orbiter uses the ALT mode of the PRCS, or the Orbiter enters free drift without active attitude control. (The payload must be compatible with the attitude control options defined in section 10.2.5, Free Drift.) Which event actually occurs depends on which jets fail. If the Orbiter down modes to free drift, it will be about all three Orbiter body axes. Primary jets must then be selected in order to reestablish attitude hold.

The payload must be compatible with a PRCS mode of control for all required operations with the exception of short-term payload activities or configuration change periods.

The payload must be compatible with PRCS closed loop automatic attitude control (attitude hold and attitude maneuvers) for any configuration, including docked or berthed configurations, that is to be held for more than two hours.

For short term activities or configurations (maintained for less than two hours), the payload must be compatible with both VRCS auto attitude control and at least PRCS ALT mode or manual minimum impulse attitude control. Multiple activities or reconfigurations requiring manual impulse attitude control are limited to a cumulative two-hour period per crew work day.

FORWARD REACTION CONTROL SYSTEM MODULE

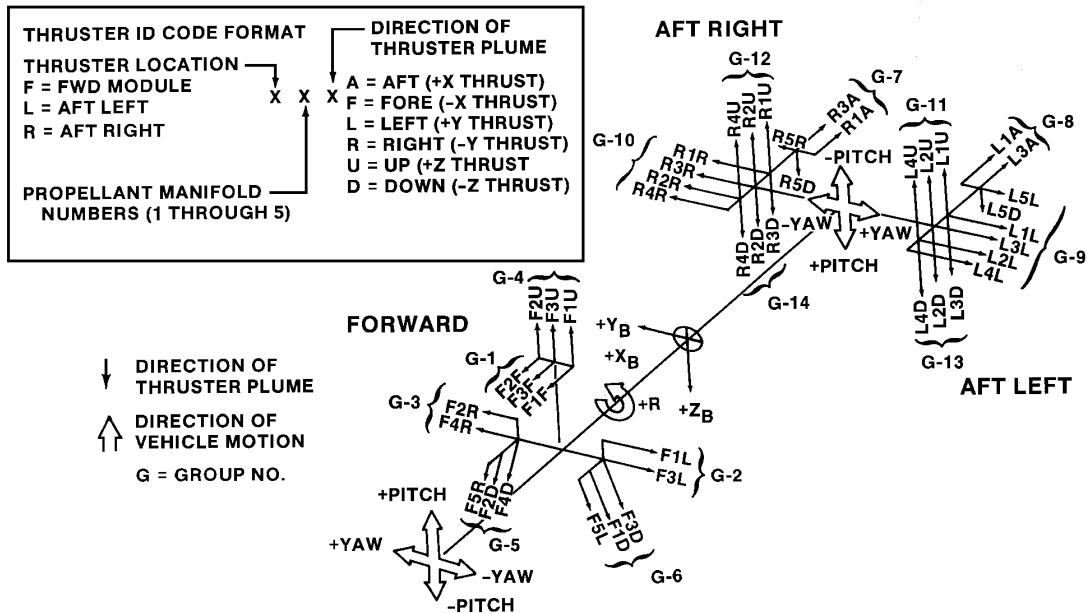
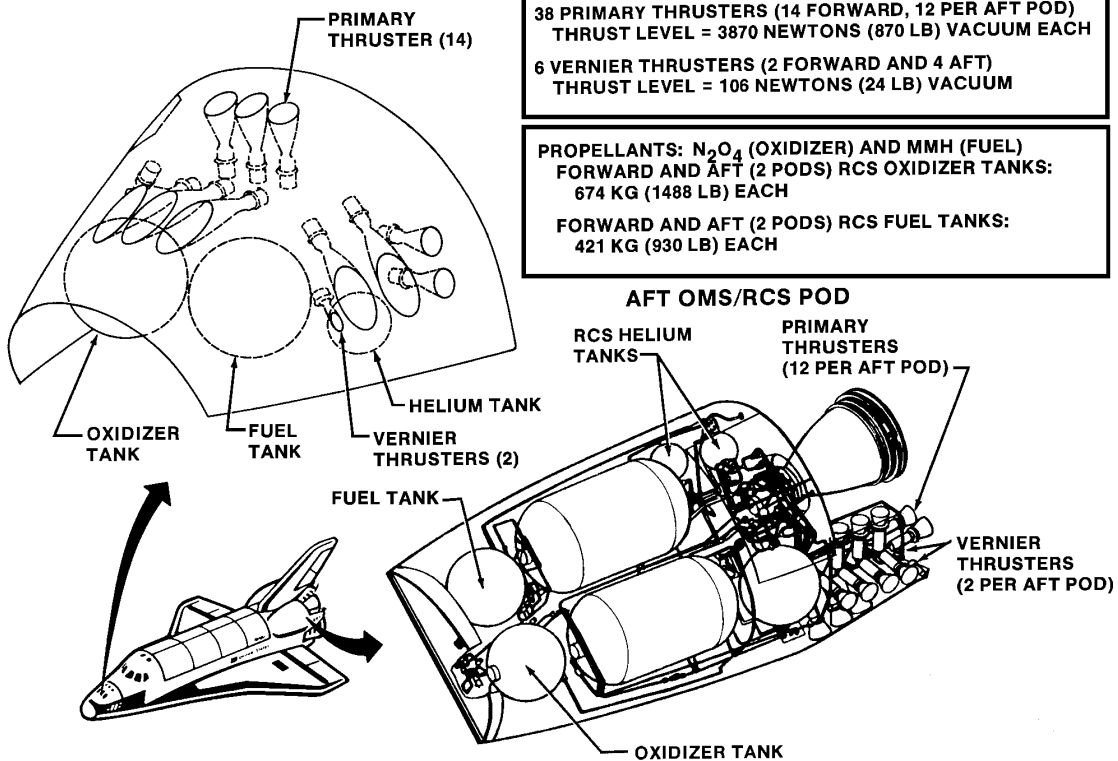


Figure 10-1.- Reaction control system jet locations and directions of thrust.

10.2 Attitude Control Options

Attitude control options include: remaining in a desired attitude (attitude hold), maneuvering from one attitude to another, rotating about a given axis, tracking a specified target, or establishing free drift. These control options are explained in the sections that follow. Two general categories of maneuvers are available: (1) Automatic (auto) control is performed using the on-orbit DAP. (2) Manual control is performed by Shuttle crewmembers via hand controllers similar to control sticks used to fly aircraft.

In the event of failures which preclude attitude control, the payload must be compatible with the provisions of NSTS 1700.7. If jettison is used as a method to satisfy the safety requirement, an analysis must be performed to ensure that the combined vehicle rates will not preclude a safe separation.

Automatic attitude control includes the attitude hold, maneuver, rotation, and target track options. These, as well as the free drift and manual control options, are discussed below.

10.2.1 Attitude Hold

The Orbiter can maintain a desired attitude relative to a specified reference frame. Current frames include but are not limited to inertial (M50) and LVLH. Attitude hold may be done while in manual or auto control mode.

Inertial Attitudes

Inertial attitudes are defined in the DAP software by an Euler-sequenced pitch, yaw, roll, (P, Y, R) series of rotations of the Orbiter body axis system (OBAS) relative to the chosen inertial reference frame. Note that roll, pitch, yaw (R, P, Y) is the standard way Orbiter inertial attitudes are written in SSP flight documents.

LVLH Attitudes

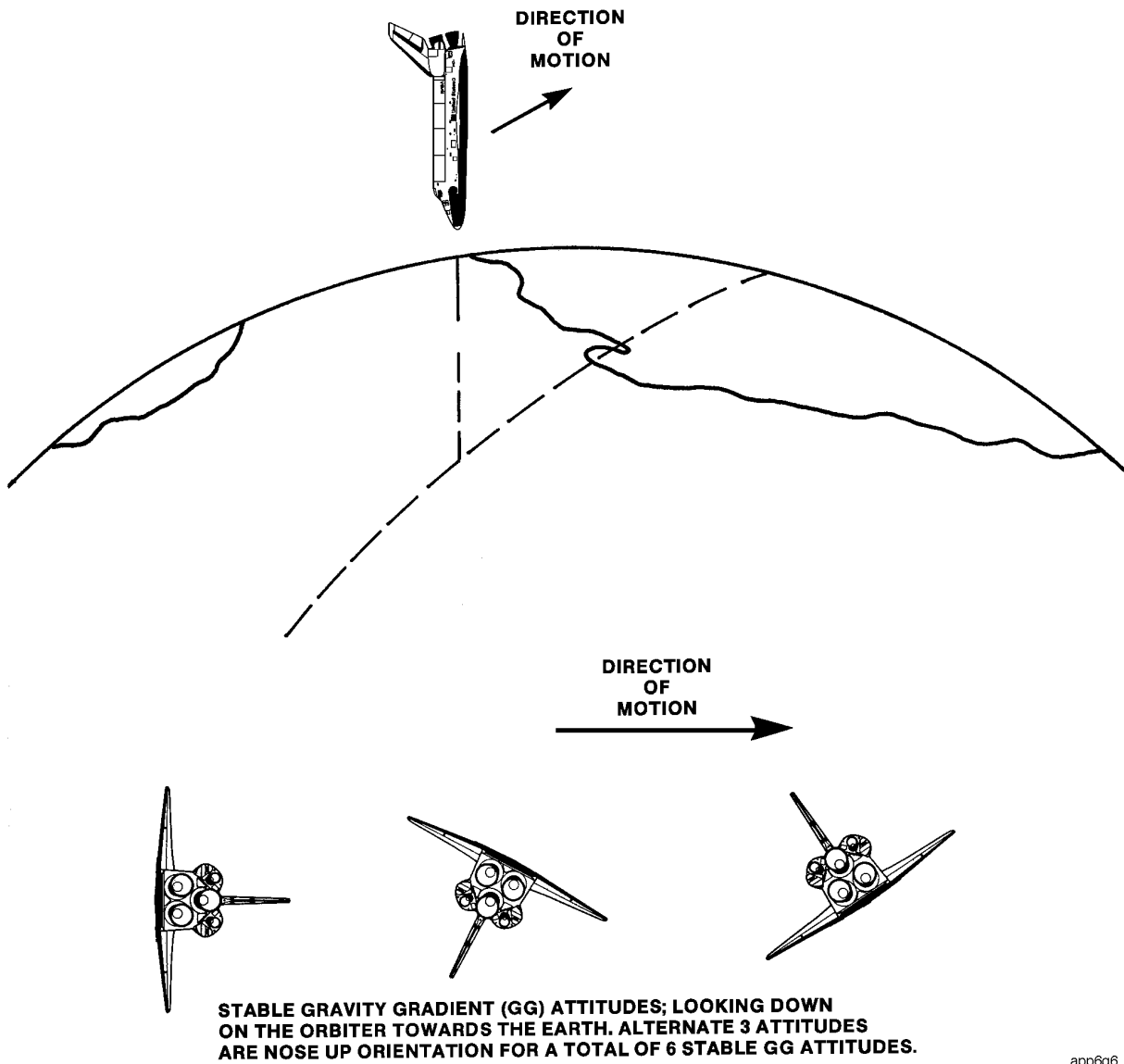
LVLH attitudes are currently maintained using the target track option. However, for visualization and communication purposes, LVLH attitudes are often defined in flight documents using the same Euler rotation

sequence as outlined for inertial attitudes. When LVLH attitudes are defined by a set of (R, P, Y) numbers, these numbers must be converted to a body vector and an omicron value. The track option uses these parameters to maintain the specified LVLH attitude. (See Track Option for further details.)

Gravity Gradient Attitudes

Gravity gradient attitude hold is theoretically a method of maintaining a stable Orbiter attitude without the use of RCS jets. Payloads normally request this attitude in order to minimize or inhibit RCS jet firings while remaining in a stable attitude. There are six stable gravity gradient attitudes as shown in Figure 10-2. One attitude is payload bay forward, pointing along the Orbiter's velocity vector. Two other attitudes are either left or right wing forward but not aligned with the velocity vector. For either of these three attitudes the Orbiter's nose or tail may be pointed toward the Earth. Note that these are representative attitudes. Actual gravity gradient attitudes for a given flight must be calculated pre-mission. Expect errors in the computed attitudes due to uncertainties in the knowledge of the numerous parameters that affect gravity gradient attitudes.

In general, gravity gradient attitudes are designed to balance torques due to gravity gradient and aerodynamic drag (aerodrag). Under ideal conditions, the torques these forces create on the Orbiter will sum to zero and the Orbiter will remain in the resulting (gravity gradient) attitude. This attitude is stable since the gravity gradient and aerodrag torques act as restoring torques. These moments will vary and will not remain balanced. Therefore, attitude deviations occur. If RCS jets are being used to "control" the gravity gradient attitude, jets may fire. If jets are inhibited (free drift), expect the Orbiter to oscillate about the gravity gradient attitude. Attitude deviations and oscillations are generally due to atmospheric variations that affect aerodrag torques. For free-drift gravity gradient attitudes, the Orbiter attitude and rate errors at the instant free drift is initiated may also affect attitude deviations and oscillatory motion. Typically, gravity gradient attitudes have been observed to oscillate in a sinusoidal wave fashion. Analyses of flight data indicate



app6g6

Figure 10-2.- Gravity gradient attitudes.

pitch and yaw oscillations of ± 2 to 8 degrees and roll oscillations of ± 10 to 30 degrees may be expected. A slow buildup to steady-state conditions may occur over a period of two to four orbits. It should also be noted that at times the gravity gradient attitude is too stable and no RCS jets fire for an extended period of time. This can cause the RCS jets to fail as they get too cold. To avoid this condition, if they gravity gradient attitude is to be held for an extended period, the attitude is biased to ensure that jets will fire at a sufficient rate to preclude a leak due to temperature.

10.2.2 Maneuver

The maneuver option is used to maneuver to an inertial attitude. The desired attitude is specified by a Euler-sequenced pitch, yaw, roll series of rotations of the Orbiter body axis system relative to the Mean of 1950 (M50) reference frame. Once the desired attitude has been reached, the DAP will command RCS jet firings to maintain the Orbiter in this attitude. How tightly attitudes are maintained is normally determined by values assigned to the attitude deadband and rate deadband DAP parameters. The rate at which the Orbiter maneuvers from one attitude to another (maneuver rate) is determined by the discrete rate DAP parameter. These parameters are discussed in a later section. At present, the maneuver option cannot be used to maneuver to or maintain LVLH attitudes.

10.2.3 Rotation

The rotation option is used to rotate about a specified Orbiter body-referenced vector. This vector (or line of sight) determines the axis of rotation which is held fixed in inertial space. Therefore, these rotations are inertial. The axis of rotation is normally limited to the Orbiter's X, Y, or Z body axis. The Y and Z axes correspond to the Orbiter's principal pitch and yaw axes of rotation, respectively. The principal roll axis is approximately 2 degrees below the X body axis. However, roll rotations are normally done about the X body axis since there is little difference in performance between the two axes.

Rotation rates are normally established while the DAP is in auto control. An exception is LVLH rotations which are discussed later. Under auto control, the rate of rotation is determined by the

discrete rate DAP parameter. Allowable rates vary depending upon which jets (verniers or primaries) are used to command the rotation. Standard Orbiter operations use rates from 0.008 up to 0.5 degrees/second. In addition, standard operating procedures dictate that vernier jets are not normally used to create rate changes greater than 0.2 degrees/second. Rates greater than 0.2 degrees/second are normally initiated (and stopped) using primary jets or staging procedure using vernier jets at increments of 0.2 degrees/second. Once established, large rates may be maintained using vernier jets. Deviations to these standard operating procedures may be requested and will be considered on a case-by-case basis.

Another type of rotation the Orbiter is capable of doing is an LVLH rotation. In this case, the axis of rotation is held fixed relative to the LVLH reference frame. No option currently exists to control LVLH rotations in the auto mode. Therefore, these rotations can only be done under manual control. Rotation rates are initiated by manual deflection of the rotational hand controller. Rotations commanded manually may only be performed about one of the three Orbiter body axes (X, Y, or Z).

10.2.4 Target Track

The target track option is used to maintain a line of sight (or pointing vector) from the Orbiter to a specified target. Only one pointing vector and one corresponding target may be specified at a given time. The following may be used as targets:

- 1) Another orbiting vehicle
- 2) The center of the Earth
- 3) An Earth-fixed target (specify target's latitude, longitude, and altitude.)
- 4) The center of the Sun
- 5) A celestial target (specify target's right ascension and declination.)

Pointing vectors (also known as body vectors) are referenced to the Orbiter body axis system. Specifying the pointing vector and the target is not enough information to define a unique Orbiter attitude. A unique attitude is not defined

until the orientation about the pointing vector is also specified. This orientation is specified by a parameter called omicron.

The Orbiter's ability to track a target is governed by the maximum line-of-sight rate the Orbiter must achieve in order to keep the desired pointing vector on a given target. If another orbiting vehicle or an Earth-fixed object is specified as the target, the line-of-sight rate will vary as the Orbiter-to-target relative position changes. The line-of-sight rate will be greatest when the Orbiter is closest to the target. Normally, this maximum rate should not exceed the Orbiter's maximum rotation rate as discussed under the rotation option in this section. Line-of-sight rate is an angular velocity that typically varies with time. Therefore, there is a varying angular acceleration the Orbiter must be capable of achieving in order to vary the line-of-sight rate as required to keep the line-of-sight pointed at the target. In general, the maximum required angular acceleration should not exceed the angular acceleration the RCS jets can provide. Note that vernier jets provide less acceleration than primary jets. In addition, acceleration values may vary for positive versus negative rotations about the same Orbiter body axis. (See RCS acceleration tables in ICD 2-19001.)

For typical Orbiter altitudes (160 to 180 nmi) most ground target tracking is done with primary rather than the vernier jets. The reason for this is the angular acceleration required to maintain the varying tracking rate usually exceeds the capability of the vernier jets.

10.2.5 Free Drift

Free drift is normally defined as inhibiting the on-orbit DAP from actively maintaining attitude control. In turn, this inhibits RCS jet firings. The free drift option is available for only very short periods of time and must be specifically negotiated in the IP. Free-drift requirements for long periods of time are not accepted. Allowable durations of attitude free drift are a function of comanifested payload and Orbiter constraints and must be analyzed on a flight-specific basis. For preliminary payload design and operations planning activities, times of up to one hour can be considered for dedicated missions. The

Orbiter is free to return to active attitude control whenever necessary.

Some payload customers require free drift in order to prevent disturbances caused by RCS jet firings or to avoid contamination from jet plumes. Free drift may be established about one, two, or all three Orbiter body axes. Since there is no attitude control, the Orbiter will not remain in the attitude it was in at the start of free drift. During such times, payload attitude constraints (for example, communications or thermal) may not be guaranteed. Also, on-board command capability may be necessary to reconfigure the payload depending on specific requirements. Some limited attitude control may be obtained if the free drift start attitude is a gravity gradient attitude. (See Gravity Gradient Attitudes in section 10.2.1 for further details.)

Instead of totally inhibiting active attitude control, the benefits of free drift may also be obtained by selecting attitude and rate deadbands (DAP parameters) that are large enough so that these parameters are not exceeded during the required free-drift period. As long as the Orbiter's attitude and rate errors do not exceed the selected deadbands, jets will not fire. A possible disadvantage of this latter method is that the duration of time during which jets do not fire may not be as long as if active attitude control were deselected. The duration of any free-drift period may be affected by Orbiter thermal constraints. Free-drift duration may also be affected by constraints or operating restrictions imposed on various Orbiter systems.

10.2.6 Manual Control

Manual attitude control during on-orbit operations is normally limited to performing rotations, holding an inertial or LVLH attitude, and doing fine attitude adjustments.

10.3 On-Orbit DAP Parameters

The on-orbit DAP has several parameters that may be specified through crew inputs. These parameters are used to select the rate at which the Orbiter maneuvers and to choose the allowable attitude error the Orbiter maintains during an attitude maneuver or during attitude hold. The on-orbit DAP uses a phase-plane

attitude control system. Attitude deadband and rate deadband are used to define the phase plane for each Orbiter body axis. DAP parameters that are usually of interest to the customer are:

- a. Discrete rate - Rate at which the Orbiter will maneuver from one attitude to another. Also the rate at which the Orbiter will rotate about a specified axis. (See Rotation Option.) This parameter may be used for both auto and manual attitude control.
- b. Pulse rate - The change in rotation rate about the Orbiter's X, Y, or Z body axis for each pulse commanded via the crew's rotational hand controller. This parameter only applies to manual attitude control.
- c. Attitude deadband - A parameter used to define how far out of a desired attitude the Orbiter can drift before RCS jets fire to correct for the drift. Attitude deadband gives an indication of how accurately a desired attitude is maintained.
- d. Rate deadband - The maximum rate error allowed in each Orbiter body axis. If this value is exceeded in any one of the three axes, jets fire to null out the error.

Attitude and rate deadbands are selected to minimize propellant consumption while satisfying payload and Orbiter pointing requirements.

10.4 Pointing Capabilities and Accuracies

Pointing refers to the act of aiming a fixed line of sight at a given target. Line of sight is treated as a vector referenced to the Orbiter body axis system. Fixed line of sight means the vector is not moveable with respect to the Orbiter structure. The boresight of a payload instrument or Orbiter sensor may be modeled in the DAP using such a vector. The DAP will accept only one pointing vector and one corresponding target at a time. If the desire is to point two lines of sight at two separate targets, ground processors may be used to compute an attitude that will point the first vector directly at one target, while pointing the second vector as close as possible to the second target. Categories of

potential targets are the same as listed for the target track, attitude control option. Pointing may be accomplished while holding a desired attitude (attitude hold) or while maneuvering the Orbiter in order to keep a pointing vector aimed at a target. In the latter case, Orbiter maneuvering is required due to relative motion which may occur between the Orbiter and some targets. Although some pointing operations may be done manually, they are usually performed using automatic attitude control.

Potential error sources that may affect how accurately the Orbiter points a payload (or pointing vector) include but are not limited to the following:

- a. Orbiter IMU errors
- b. Orbiter on-orbit navigation errors (accuracies)
- c. Structural alignment uncertainty between the payload (or pointing instrument) and Orbiter navigation base. This alignment uncertainty includes the effects of Orbiter structural bending due to thermal distortions and gravity- (g-) force unloading.
- d. Orbiter flight control system software timing delays
- e. Attitude errors due to selected attitude and rate deadbands. (See DAP Parameters.)
- f. Errors in the target's state vector or the Orbiter's knowledge of a target's location
- g. Orbiter drift during free drift periods. (Note: Some payload customers may desire pointing operations while the Orbiter is in free drift in order to prevent disturbances caused by RCS jet firings or to avoid contamination from the jet plumes.)

Pointing accuracies are typically specified in terms of half-cone angles. The cone serves as a geometrical representation of the pointing error about the pointing vector (or line of sight). The accuracies outlined in the sections that follow are based on using the Orbiter's IMU's for attitude information and assuming an attitude deadband of 0.1 degree per axis. The numbers take into account the uncertainties from all the error sources listed above and assume no

extreme thermal conditions are encountered on orbit. Pointing accuracies may be improved considerably if an on-orbit calibration of the pointing vector (line of sight) can be achieved using a payload-mounted sensor.

10.4.1 Pointing Accuracies During Inertial Attitude Hold

Pointing accuracies while maintaining an inertial attitude are predominantly affected by the following:

- a. Orbiter IMU errors
- b. Structural alignment uncertainties between the payload (or pointing instrument) and Orbiter navigation base
- c. Selected DAP attitude deadbands

A vector referenced to the plane of the payload longeron/cradle interface may be maintained to an inertial pointing accuracy of ± 1.0 degrees for durations of up to 1.0 hour, subsequent to which IMU realignment is required. Active IMU realignment can require interruption of attitude hold for durations of up to 35 minutes, and the vehicle may require maneuvering to acquire the necessary stars. Pointing duration can be extended beyond one hour (for less frequent active IMU realignment) through IMU inflight calibration. The 3-sigma pointing accuracy degradation rate for inertial targets is 0.105 degrees/hour/axis.

10.4.2 Pointing Accuracies During LVLH Attitude Hold

Pointing accuracies while maintaining an LVLH attitude are predominantly affected by the same errors listed for inertial attitude hold. Additional errors include Orbiter on-orbit navigational errors (accuracies). A vector referenced to the plane of the payload longeron/cradle interface may be maintained to a local vertical pointing accuracy of ± 1.0 degrees for durations of up to 1 hour after IMU realignment. Pointing duration can possibly be extended beyond this time by IMU inflight calibration and/or by passive IMU realignment. The 3-sigma pointing accuracy degradation rate for LVLH targets is 0.105 degrees/hour/axis.

10.4.3 Pointing Accuracies While Tracking an Earth-Fixed Target

Pointing accuracies while tracking an Earth-fixed target are predominantly affected by the same errors listed for inertial attitude hold. Additional errors may include Orbiter on-orbit navigational accuracies and errors in the Orbiter's knowledge of the target's location.

A vector referenced to the plane of the payload longeron/cradle interface may be maintained to an Earth-fixed pointing accuracy of ± 1.0 degrees. Continuous Earth-surface fixed-target pointing can be maintained for durations of up to 0.5 hours after IMU realignment. Pointing duration can possibly be extended beyond this time by IMU inflight calibration and/or by passive IMU realignment. The 3-sigma pointing accuracy degradation rate for Earth-surface fixed targets is 0.105 degrees/hour/axis.

10.4.4 Pointing Accuracies While Tracking an Orbiting Target

Pointing accuracies while tracking an orbiting target are predominantly affected by the same errors listed for inertial attitude hold. Additional errors may include Orbiter on-orbit navigation accuracies and errors in the target's state vector or the Orbiter's knowledge of a target's location.

10.4.5 Pointing Accuracies While Executing the Rotation Option

Pointing accuracies while executing the rotation option are predominantly affected by the same errors listed for inertial attitude hold. Additional errors may occur due to Orbiter flight control system software timing delays. Depending on the attitude and rate deadbands selected, rotation rate may also affect pointing accuracy.

10.4.6 Pointing Capability for Non-RMS Deployable Payloads

The Space Shuttle is capable of pointing the Orbiter structural interface with a payload to within one degree of the required inertial attitude when using the VRCS. The angular rate at deployment shall be no greater than 0.01

degrees/second/axis for vernier control, or 0.2
degrees/second/axis for primary control.

Navigation Accuracy and Tracking Requirements

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On-orbit navigation is currently based on data from the ground tracking stations of the Space Network (SN) and the Tracking Data Relay Satellite System (TDRSS). The main advantage of the TDRSS is increased Orbiter visibility. This allows the collection and processing of navigation data and the state vector uplink to occur much closer in time to the event (for example, maneuver or payload state vector initialization) to be supported than is possible with only the ground tracking stations.

- a. Orbiter attitude change maneuvers using either primary or VRCS
- b. Attitude hold using the PRCS
- c. Vents, dumps, purges, or other thrusting
- d. Atmospheric drag uncertainties (for orbits at 150 nmi or lower)
- e. Time since the last state vector update

11.1 Navigation Accuracies - General Information

Navigation accuracies are dependent on many factors. These apply for both RMS and ejectable payloads.

- a. Accurate navigation can be achieved no earlier than four and a half hours after liftoff. This time refers to the end of the tracking arc and does not include the time required to process the data and uplink the vector.
- b. Velocities created by the deployment of a payload will increase errors in the navigation.
- c. The navigation data gathering/processing/uplink interval is up to seven hours for the ground tracking stations and five hours and fifteen minutes for TDRSS).

11.2 Navigation Accuracies - Factors

The navigation accuracy depends on unanticipated disturbances to the orbit. Many factors can increase errors in the navigation. Some of these factors are listed below:

Electrical Power

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The power reactant storage and distribution (PRSD) system supplies cryogenic hydrogen and oxygen to three fuel cells to produce electrical power for the mission. The number of tank sets flown is partially a function of the power loads needed to meet both payload and Orbiter requirements.

refer to Data Requirements for the Flight Planning Annex, NSTS 21000-A02.

Payload electrical requirements must be documented in IP Annex 2 unless the electrical power analysis group deems that an Annex 2 is unnecessary based on the power and energy requirements in the IP. This includes a description of the electrical characteristics of equipment to be powered and the on/off times for the equipment. These requirements must be specified for the customer's equipment. Payload equipment which must have electrical characteristics specified includes baseload equipment, thermostatic equipment, and any other equipment requiring Orbiter power. In addition, the customer must provide a list of Orbiter equipment that is necessary for payload use, along with usage durations for each piece.

The cryogenic consumables budget covers payload power requirements for the nominal mission during and mission extension (additional) days up to the energy limit set forth in the IP. Power requirements for contingency scenarios, such as alternate deployment opportunities, are not included in the cryogenic consumables budget, but are included in the Annex 2 for development of consumables contingency cases, and are presented to the SSP as impact statements on the delivered consumables budget. Also included in the consumables budget are two landing attempts on the nominal entry day, two weather wave-off extension days with one landing attempt on each day, and cryogenic system residuals and measurement uncertainty.

For more specific information and definition of power usage requirements, refer to NSTS 07700, Volume XIV, Appendix 3. For additional information on electrical power data requirements,

Thermal Constraints

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For thermal reasons, the Orbiter is required to be in certain attitudes for various lengths of time depending on the orbit, length of time in the previous attitude, payload activity, etc. For more information regarding thermal requirements and capabilities, refer to NSTS 07700, Volume XIV, Appendix 2.

14.1 Acceleration/Disturbance Levels

14.1.1 Drag Accelerations

Drag effects decrease as the height of the orbit increases and are minimal above 160 nmi compared to other perturbation sources. Drag effects on the Orbiter are also a function of the Orbiter's attitude. For example, a nose-forward local vertical attitude will produce the minimum drag effect.

14.1.2 Dynamic Disturbances

Vehicle perturbations will occur during on-orbit operations from several sources including crew movement, dumps, equipment transfers, experiment operations, and thruster firings. Many of these perturbations can be controlled by scheduling; however, requirements that limit crew activities will need to be negotiated. Constraints on thruster firings (for instance, free drift or gravity gradient attitude control modes) are defined in ICD 2-19001. Critical attention to crew activity and vehicle attitude control timelines will be necessary when planning microgravity experiments. Measurement of disturbance levels at the experiment locations is the responsibility of the customer.

14.1.3 Jet Accelerations

During orbital periods, the magnitude of acceleration due to thrusting is a function of the vehicle's weight and the jets being fired. For purposes of assessing effects on experimental data, typical rotational and translational accelerations are listed in ICD 2-19001.

14.2 Contamination

The Orbiter frequently performs dumps, purges, vents, and jet firings that affect the level of contamination in the payload bay and around the vehicle. The level of contamination is a function of the event causing the contamination and the placement of the payload with respect to the Orbiter. All causes and effects of contamination are documented in System Description and Design Data - Contamination Environment, NSTS 07700, Volume XIV, Appendix 1.

How the Integrated Mission Timeline Is Built

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The process the SSP uses to transform the customer's IP, IP Annex, and payload operations working group (POWG) mission planning information into an integrated timeline is described below. Each mission or payload manifest presents unique planning situations and may vary from this general description.

15.1 Early Mission Development

The planning process for the Shuttle mission begins after the mission manifest has been established. The payload requirements specified in the IP and its Annexes are evaluated to establish key mission drivers such as deployment opportunities or time-constrained events. These are in turn evaluated against SSP constraints, trajectory requirements, and the needs of other shared cargo partners. Variations of the trajectory and the mission activities are iterated until a flight profile is developed which meets all mission objectives and provides the highest probability of mission success. Since this is the first integrated timeline produced for a given mission manifest, the resulting mission plan will be assessed internally by the SSP, and then jointly by the SSP and the customers at the Cargo Integration Review (CIR). This mission timeline (including changes resulting from the CIR) will then be published as the preliminary Flight Plan.

15.2 Detailed Timeline Development

For the post-insertion and deorbit prep mission phases, timeline constraints on payload operations dictate that little payload activity occur. The on-orbit phase is the most flexible for payload

operations. Payload timelines are managed within a POWG.

This working group includes operational representatives of both the customer and the SSP. The members of the group will meet several times between the request for launch services and the actual launch. In these meetings, several iterations of procedures and timelines will be worked in order to optimize the use of time on orbit and the probability for mission success.

As payload requirements are developed further through use of the Annexes and POWG's, a more detailed iteration of the trajectory will also be developed. It will incorporate further refinements of requirements, changes resulting from new data or a new launch date, and improved knowledge of mission events (a byproduct of the initial planning cycle). Potential conflicts among the payloads are worked to provide an acceptable mission timeline.

This planning cycle leads to publication of the basic edition of the Flight Plan which reflects the details of the mission timeline and includes all the payload requirements to be satisfied on the mission. After this publication, the Flight Plan (and all other Flight Data File (FDF) articles) are placed under configuration control. Subsequent changes to the Flight Plan or FDF require submittal of the details of the change and rationale justifying incorporation. This change must then be approved by the Crew Procedures Control Board (CPCB), which consists of representatives of the various disciplines involved in the mission. After a one-month review time, the basic Flight Plan and related FDF products will be reviewed with the customer at the Flight Operations Review (FOR). Any discrepancies between customer requirements and the mission plans are identified and actions taken to resolve the conflict.

15.3 Final Mission Timelines

After the basic Flight Plan is published, only mandatory changes will be made to the mission timelines and procedures. Stability of these products is crucial for crew and flight controller training with near flight-ready data, as well as for use as the basis for detailed consumables projections and final mission planning. This last iteration of the timeline, the final Flight Plan, also incorporates the latest and most accurate iteration of the trajectory and any changes which may result from lessons learned in integrated simulations and procedure validations.

Changes from the basic to the final Flight Plan should be small refinements resulting in the flight-ready version of the mission timeline rather than late changes to customer requirements. Due to the highly integrated nature of the timeline for multiple payloads, such changes would require massive revisions of the timeline and affect the planning of the other payloads on the mission. This cannot be accommodated close to flight.

The final Flight Plan is published about six weeks prior to launch and is the primary product for integrated training. All procedures and timelines undergo a final validation review before certification for flight. After review by the flight crew and about ten days before launch, the flight copies of the FDF are shipped to Kennedy Space Center.

15.4 Customer Participation

Each payload customer's PIP and Annexes, as well as inputs made at the Payload Operations Working Groups (POWG's), are factored into a mission timeline for the entire cargo. The customer is involved in these key functions:

- the Cargo Integration Review, from which the preliminary Flight Plan is produced;

- meetings of the POWG, which manages procedures and timelines leading to the basic Flight Plan; and

- the FOR, at which the basic FDF products are formally reviewed.

Acronyms and Abbreviations

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ACS	attitude control system	MIP	Mission Integration Plan
aerodrag	aerodynamic drag	NASA	National Aeronautics and Space Administration
AFD	aft flight deck	nmi	nautical mile(s)
AIO ₂	aluminum oxide	NSTS	National Space Transportation System
ALT	alternate		
ASE	airborne support equipment		
auto	automatic		
CCTV	closed circuit television	OBAS	Orbiter body axis system
c.g.	center of gravity	(P, Y, R)	pitch, yaw, roll
CIR	Cargo Integration Review	PIP	Payload Integration Plan
COAS	Crew Optical Alignment Sight	POCC	Payload Operations Control Center
CPCB	Crew Procedures Control Board	POWG	Payload Operations Working Group
CRT	cathode ray tube	PRCS	primary reaction control system
DAP	digital auto pilot		
DOD	Department of Defense	(R, P, Y)	roll, pitch, yaw
ETR	Eastern Test Range	RAAN	right ascension of ascending node
EVA	extravehicular activity	-RBAR	negative position vector (beneath)
FDF	Flight Data File	RCS	reaction control system
FOR	Flight Operations Review	revs	revolutions
fps	foot (feet) per second	RF	radio frequency
g	gravity	RMS	remote manipulator system
GCS	Generic Command Server	RR	rendezvous radar
GMT	Greenwich Mean Time	RTS	remote tracking station
GNC	guidance, navigation, and control	SPDS	Stabilized Payload Deployment System
GPS	Global Positioning System	SRM	solid rocket motor
HHL	Handheld Laser	SSP	standard switch panel
IMU	inertial measurement unit	TBS	to be supplied
IP	integration plan	TCS	trajectory control sensor
JSC	Johnson Space Center	TDRS	Tracking and Data Relay Satellite
L-	launch minus	TDRSS	Tracking and Data Relay Satellite System
lb	pound(s)	+VBAR	positive velocity vector (forward)
LVLH	local vertical/local horizontal	VRCS	vernier reaction control system
m	meter(s)	+ZVV	+Z velocity vector (Orbiter belly forward)
M50	Mean of 1950		
MCC-H	Mission Control Center-Houston		
MCDS	Multifunction CRT Display System		
MET	mission elapsed time		

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